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THE NUTRITION OF GARDEN BEET IN RELATION TO SEED PRODUCTION

By S. W. BERESFORD* and A. A. JACKSON

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THE literature on the nutrition of seed crops is sparse and usually more concerned with yield than with quality. The possible effect of the nutrient status of the soil on germination has rarely been considered, although unexplained variations in germination frequently occur and cannot always be accounted for either by weather conditions or by treatment after harvest, which are the usual explanations offered.

Most investigators of the nutrition of beet for seed have been concerned with the sugar beet crop and confirm the advantages of dunging before transplanting and of the application of nitrogen in the spring of the second year. This was shown by Mann and Barnes (1945) at Woburn who obtained increased seed yields when dung was ploughed in before transplanting, and by Ellerton (1947) who obtained increased yields when he applied sulphate of ammonia in March (40 and 80 lb. of nitrogen per acre), but not when he gave a further dressing in June. At Cambridge, similar dressings of sulphate of ammonia resulted in increased yields in the dry year of 1955, but not in the wet year of 1956 (N.I.A.B., 1956). American and Canadian work with the transplanted crop also confirms the value of nitrogen (Webster, 1942; Tolman, 1943 ; Schudel, 1952).

Some information has been published on the germination of sugar beet in relation to the nutrition of the parent crop, but the results are somewhat conflicting, probably because of differences in environment. In the U.S.A., Pultz (1937) did not obtain any significant difference in germination following a moderate application of sulphate of ammonia (150 lb. of nitrogen per acre), although Pendleton (1954) obtained an increase due to nitrogen (300 lb. per acre) and phosphate (200 lb. per acre) together. Snyder (1959) similarly observed improved germination of seed obtained from plants growing in water culture, as a result of giving an increased level of nitrogen ; in Germany Rabbethge (1956) stated that poor seed was obtained if the level of phosphate was not adequate. At Woburn (Mann and Barnes, 1945) the application of dung gave an increase, and the application of sulphate of ammonia (45 lb. of nitrogen per acre) a slight but not significant decrease in the germination of seed saved from plants grown with these treatments.

The work at Wye was planned to investigate further the effect of the environment of the mother plant on seed quality and the following account describes the first part of the work, namely the relationship of seed yield and quality to concentration of N, P and K in the sand culture in which the plants were grown in the second year. At this stage of the work no attempt was made to grow the plants from seed to seed in an artificial medium.

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Materials and methods.

Seed of the long-beet variety, Cheltenham Green Top, was sown in the field on 15th July 1958. On the 23rd March 1959 a uniform sample of the young plants (stecklings) was transplanted into pot sand culture and grown on to seed by a method based on the Long Ashton sand culture technique (Hewitt, 1952). The stecklings, which had a maximum diameter of about 1 cm. and a mean weight of 10 gm., were transplanted three per twelve-inch concrete pot. At the time of transplanting only leaf-bud primordia were visible ; the structure of the inflorescence was visible in sections taken from stecklings still growing in the field a month later. It was assumed, therefore, that application of the different treatments had started before flower formation had reached an identifiable stage, although allowance must be made for the limited nutrient reserves contained in the tap-roots of the young stecklings.

Eight treatments were given : two levels each of N, P and K combined factorially, with three replications. When N, P or K was present in a treatment at the higher of the two levels, the concentration was approximately equal to that of the element in the Long Ashton standard nutrient solution. The lower treatment level was zero until early July, when concentrations of N, P and K in all solutions were increased by amounts equivalent to 10% of the higher level, for by this time plants in some treatments were beginning to show severe deficiency symptoms and our purpose was to produce seed under low N, P and K conditions, not to prevent seeding. The composition, before and after the increase, is given in Table I, the varying concentrations of Na and SO_4 resulting from the substitution of salts in the deficiency treatments, e.g. K_2SO_4 for KNO_3. The complete solution contained N, P_2O_5 and K_2O in the proportions of 1·0:0·45:1·12.

TABLE I.

Concentrations of nutrients (m.eq./L) in complete and deficiency solutions used in sand cultures.

Nutrient	Solution set No.*	Treatment							
		NPK	NP	NK	PK	N	P	K	Nil
NO_3	1	15·0	15·0	15·0	—	15·0	—	—	—
	2	16·5	16·5	16·5	1·5	16·5	1·5	1·5	1·5
PO_4	1	4·0	4·0	—	4·0	—	4·0	—	—
	2	4·4	4·4	0·4	4·4	0·4	4·4	0·4	0·4
K	1	5·0	—	5·0	5·0	—	—	5·0	—
	2	5·5	0·5	5·5	5·5	0·5	0·5	5·5	0·5
Ca	1	10·0	10·0	10·0	10·0	10·0	10·0	10·0	10·0
	2	11·0	11·0	11·0	11·0	11·0	11·0	11·0	11·0
Na	1	4·0	9·0	1·33	4·0	5·0	4·0	1·33	1·33
	2	4·4	9·9	1·73	4·9	5·9	4·9	2·23	2·23
SO_4	1	3·0	3·0	4·33	18·0	3·0	13·0	19·33	14·33
	2	3·0	3·5	4·33	18·5	3·5	13·5	19·83	14·83
Mg and trace elements	1	Present in equal quantities in all solutions							
	2								

* Set 1 used up to 5/7/60; set 2 thereafter.

The plants were harvested individually between 21st August and 4th September, bagged and allowed to dry naturally ; the seed clusters were then removed by hand. The final cleaning of the samples removed inert matter and clusters having a diameter of less than 2·5 mm. The cleaned samples were weighed and divided into large, medium and small clusters, using sieves having holes 4·0, 3·5 and 2·5 mm. in diameter ; the three sizes of clusters were further sub-divided into those composed of 1, 2, 3 and 4 or more seeds. The relative proportions of the different-sized clusters were calculated as percentages and the number of seeds they contained was recorded. The samples were tested for germination according to the standard practice in use at the Official Seed Testing Station, Cambridge, eight replications of 25 clusters being tested for each sample. Glasshouse tests, with seed trays containing John Innes No. 1 potting compost, provided information relating to the number of seedlings produced by each type of cluster, and also made possible visual assessment of vigour.

RESULTS AND DISCUSSION.

Bolting was first noted at the beginning of May and treatment differences were soon apparent. Plants receiving the complete solution and the solution deficient in K only (NP) were similar in rate of growth and vigour, and compared favourably with the guard rows which had been planted in John Innes No. 3 potting compost. All plants started to flower at about the same time, viz. in the second and third weeks of June.

An examination of the effect of the treatments on seed quality provided information on germination, size, weight, composition and colour of the clusters ; the percentage germination of the true seeds was also obtained. A summary of the results is given in Table II and the data for the individual treatments in Table III. Although the treatments have been designated NPK, NP, NK, etc., it should be emphasized that the deficiency of N, P or K in the treatments was not absolute throughout the whole period of growth.

The results in Table II have been tabulated according as the main or interaction effects of the three elements at the two different levels were considered to be beneficial or otherwise to the purchaser of the beet seed. Increased yield and better germination were obviously of value but smaller and lighter-weight clusters were considered harmful because of the apparent association with poorer germination ; this also applied to the darker clusters. A high number of seeds per cluster was also considered undesirable because of the need for extra thinning of young plants.

The most striking feature of the results (Table II)was the consistent reduction in germination attributable to the main N and P effects and to the NP interaction effect, this reduction being obtained even though these same three effects contributed to the general increase in yield that was obtained as a result of the higher nutrient level. Therefore, although optimum yields were probably not obtained, the higher level of N and P must have been sufficiently great, either quantitatively or in relation to the K level, to cause a reduction in germination; this would suggest that an increase in the proportion of K might have been beneficial and would probably have raised the germination of the clusters in the NPK treatment (55%) to nearer that of the K treatment (92%). Sodium has been shown to be of value to the beetroot crop (Lehr.

TABLE II.

Influence of nutrition on seed production in garden beet.

Aspect examined	Significant effects (positive)	Result	Significant effects (negative or of little practical importance)	Result
Yield of clusters	N*** K** P*** NK** NP*** PK** NPK**	Increased yield	——	——
Dry weight of plants (aerial vegetative portion)	N*** P*** NP***	Increased vegetative growth	K* PK*	Reduced vegetative growth
Cluster size	PK***	Larger clusters	P** NP** N*	Smaller clusters
Cluster weight	K* PK*	Heavier clusters	P**	Lighter clusters
Mean number of seeds/cluster	——	——	N**	more seeds/cluster
Proportion of different-sized clusters	——	——	N***	Less 2-seeded and more 3- and 4-seeded clusters
Germination of clusters (sand)	K*** NPK*** PK**	Germination increased	N*** P*** NP***	Germination reduced
Germination of clusters (soil)	K*** NPK*** NK* PK*	Germination increased	N*** P*** NP***	Germination reduced
Germination of large clusters	NPK*** K* NK* PK*	Germination increased	N*** P*** NP***	Germination reduced
Germination of 2-seeded clusters	K*** NK** PK* NPK*	Germination increased	N*** NP*** P**	Germination reduced
Germination of 3-seeded clusters	NK** K* NPK*	Germination increased	N*** P** NP**	Germination reduced
Germination of seeds	K*** NPK*** NK* PK*	Germination increased	N*** P*** NP***	Germination reduced
Cluster colour§	——	——	N	Darker clusters
Seedling vigour§	Apart from NP, vigour was not adversely affected by deficiency treatments			

Statistical significance: *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$

§ Visual assessment, not statistically analysed.

1955), so the possible effect of the varying sodium levels in the deficiency treatments (sodium nitrate replaced potassium nitrate in the K-deficient solutions) must be taken into account when considering the results. However, the differences in yield and especially in germination between the NPK and the NP treatments indicate that, for the seed crop, sodium cannot wholly replace potassium. Winter (1954) obtained shrivelled lettuce seeds from a high nitrogen and low potash treatment, phosphate being adequate, a similar result to that obtained with the beet seed at Wye.

The Wye results indicated that the poorer germination resulting from the main N and P effects, and from the interaction between these two, was not necessarily the result of the smaller clusters that were produced by these same three effects : the germination pattern of the whole sample and of the large clusters by themselves was essentially the same (Table II) although the actual values varied according to the type of cluster examined (Table III). This would tend to confirm Winter's finding that small beet clusters did not necessarily contain poor seed (Winter, 1951), and would suggest that the treatments had a far greater effect on the germination of the seeds than did the type of cluster of which they formed part.

The figures for cluster weight were based on the whole sample and, although not very conclusive, they support Winter's finding that there is a positive correlation

TABLE III.

Experimental results (totals or means of 3 plots).

Aspect examined	Treatment								
	NPK	NP	NK	PK	N	P	K	Nil	S.E.
Total yield of clusters, gm.	165	100	40	45	40	45	35	35	1·7
Total dry weight of plants (aerial vegetative portion), gm.	120	165	25	15	20	20	10	10	2·2
Mean percentage of:									
large clusters	61	46	77	84	89	73	84	74	6·1
medium clusters	15	19	15	10	7	12	9	17	2·6
small clusters	24	35	8	6	4	15	7	9	3·7
Mean number of clusters/gm.	76	114	54	55	58	85	55	58	8·2
Mean number of seeds/cluster	2·29	2·21	2·14	2·07	2·27	1·97	2·09	1·91	0·062
Mean percentage of clusters with:									
1 seed	14	21	20	9	13	15	9	22	3·2
2 seeds	54	42	52	77	54	75	74	66	4·9
3 seeds	23	31	22	13	26	8	15	11	3·4
4 or more seeds	9	6	6	1	7	2	2	1	1·2
Mean percentage germination of:									
(a) clusters (sand)	55	20	77	83	83	80	92	74	2·7
(b) clusters (soil)	59	15	69	80	73	84	90	76	3·4
(c) large clusters	66	27	75	86	79	94	93	97	3·8
(d) 2-seeded clusters	39	10	70	82	53	72	71	66	3·8
(e) 3-seeded clusters	53	25	81	83	82	100	97	87	4·7
(f) seeds	46	9	51	69	57	74	76	61	2·8

between the density of the clusters and their percentage germination, viz. the K and PK effects cause heavier clusters and better germination and the P effect is seen in lighter clusters and poorer germination.

The effect of the treatments on cluster size (the N and P effects causing smaller clusters) was similar to that on germination but, as has already been shown, these two factors were not entirely linked, because the germination of the large clusters in each sample was still governed by treatment. The increase in the number of seeds in each cluster as a result of the high N level was interesting as this would mean fewer clusters to a pound of seed and extra thinning of the young plants (the mean number of seeds per cluster ranged from 2·0—2·8 for the large and from 1·1-2·0 for the medium-sized clusters according to whether nitrogen was present at a high or low level).

The colour difference between treatments was very apparent in the different samples. All the darker samples had received the higher nitrogen level and this applied both to the experimental plants and to those guard plants which had been given a high level of nitrogen. Winter had found a link between darkness of colour and germination, but the further link with high nitrogen is interesting in view of the seed trade's liking for a " bright " sample of seed. " Bright " seed, low nitrogen and good germination appear to be related.

Strong healthy seedlings were produced by all clusters except those from the NP treatment, which had very low germination, so that it would appear that, provided the clusters have a good germination capacity, the nutrient status of the mother plant is of little consequence in relation to seedling vigour.

SUMMARY.

Garden beet seed was produced in sand culture under high and low N, P and K treatments in factorial combination and the seed examined for quality.

There were significant effects on yield, germination, cluster size, weight and colour. Although high levels of N, P and K were necessary for optimum yields, the higher levels of N and P had an adverse effect on germination which, it is suggested, could possibly be counteracted by a higher level of K.

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ROSE ROOTSTOCKS: A FIRST FIELD TRIAL

By G. D. ROWLEY

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EXPERIMENTS were begun at Bayfordbury in 1954 to ascertain the nature of rootstock influence on growth, floriferousness and general health in garden roses (John Innes Inst. Ann. Reps., 1954-9). A small-scale field trial was planted in 1954 and two further trials in 1957. Characters of practical garden value—plant size and flower yield—were scored annually and assessed by statistical analysis. Flower quality, being difficult to estimate quantitatively, especially on so limited a sample of material, could not be evaluated.

The first trial has now completed five seasons' growth from maiden plants. The site chosen had a medium-light well-drained loam sloping gently towards the East (O.S. 223) and was planted in December 1954. Eight Hybrid Tea scions, chosen to cover a range of vigour and disease susceptibility, viz. Peace, Comtesse Vandal, Emma Wright, Ena Harkness, Lamplighter, McGredy's Yellow, Mrs. Sam McGredy, and Talisman, were budded in all possible combinations on 8 of the more widely used rootstocks, viz. *canina* Pfander's, *canina* wild, *canina* Brog's, Pollmeriana, Schmidt's Ideal, Senff, *coriifolia* Laxa, and *multiflora*. From 6 plants of each combination, 4 were selected for trial and the remainder used for guard rows. After an initial weighing, the roses were planted in 4 randomized blocks at distances of 3 feet, surrounded by a single guard row. The plants were occasionally sprayed against black spot when outbreaks seemed severe and were grown without fertilizer, as this might tend to mask critical differences in behaviour.

RESULTS.

Vegetative performance.

Plant size could be accurately assessed each spring by cutting back almost to the bud union and taking the fresh weight of the prunings on a spring balance fitted with a wire cradle. For the first three years, records were also kept of the numbers of basal branches over 15 cm. long and the plant height was graded into 15 cm. categories. These were discontinued when it became apparent that fresh weight gave all the information needed.

A summary of results for the first and fifth years of the trial is given in the upper half of Fig. 1. In both years *multiflora* stocks were outstanding for plant size with most of the 8 individual scions. Pollmeriana showed great promise at first, but was surpassed after the third year. Senff, Pfander's and Laxa consistently gave the smallest plants.

Strong varietal differences showed up in the expected way and were largely independent of the rootstock variety. Thus Peace, a naturally vigorous and large-growing scion, steadily increased over the years and doubled its initial weight by the fifth year. The remaining Hybrid Teas showed, on average, less increase over the first year, Ena Harkness, Talisman and Comtesse Vandal being the more vigorous and

the remainder fluctuating around their initial size. This is not to condemn them as garden varieties : it merely indicates that their successful cultivation demands more generous treatment than the rigorous conditions of this trial, which entailed severe pruning and lack of fertilizers.

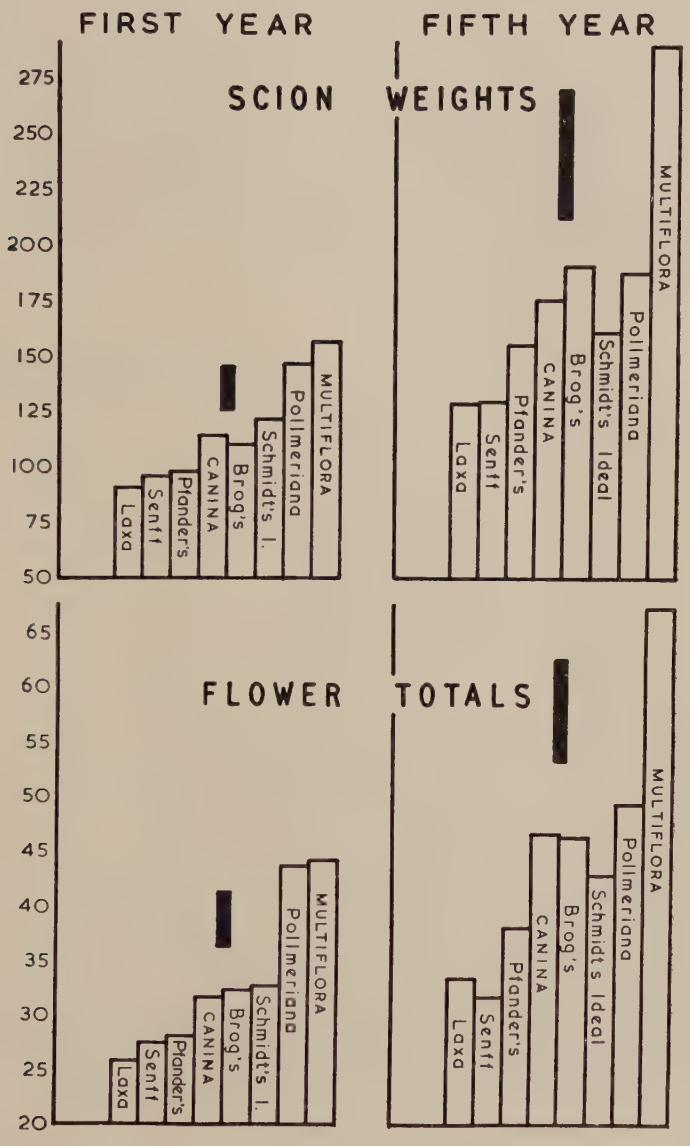

Fig. 1.

Scion weights in gm. and flower outputs for the first and fifth years of the trial, based on the means for all 8 scions on each of the root-stocks named. The vertical black lines indicate minimum separation for a significant difference.

Floral performance.

Flower yield was scored at intervals of 7 to 10 days throughout the season by counting and picking off buds just about to open. When intervals of a fortnight or longer were necessitated by bad weather, it was found that there was a risk of losing a few of the older blooms through natural abscission.

The summary of performances in the first and fifth years (Fig. 1, lower half) shows a striking similarity to that for plant weights. *Rosa multiflora* again excelled in all years and with nearly all scions, being rivalled by Pollmeriana only during the first two or three years. Laxa, Senff and Pfander's gave the smallest output of blooms. Allowing for inevitable seasonal divergencies, graphs for rootstocks and scions show a gradual mean increase each year with increasing age and maturity of the plants.

Individual scions behaved in rather different ways as regards annual increment in flower total and season of flowering, no doubt reflecting their origin from species of very different habits and environments.

Relation of plant size to flower output.

The striking similarity of the two sets of data so far discussed led to an investigation of their relationship. The analysis of variance (Table I) of flower yields includes terms for regression on plant weight.

TABLE I.

Analysis of variance.

Source of variation	Degrees of freedom	Sums of squares	Mean square
Rows (=scions)			
Regr.	1	1,969·5	1,969·5
Rem.	6	4,655·4	775·9
Columns (=rootstocks) ..			
Regr.	1	6,300·5	6,300·5
Rem.	6	86·3	14·4
Error			
Regr.	1	794·9	794·9
Rem.	48	1,774·1	36·96

Error regression coefficient $= \frac{11,516·5}{166,860} = 0·06902$ for scions.

There is thus a direct relationship between the size of the plant and the number of roses it will produce. A vigorous rootstock will give a bigger plant with any scion and in consequence more flowers, but the actual flower total is determined by the scions, which vary from one to another in flowering capacity.

Interactions.

No evidence has been found for stock/scion interactions, that is, for exceptional results due to any particular combination of rootstock and scion. In other words, any composite plant combined within itself the average effects of the particular

rootstock and scion components ; no such plant gave unexpectedly large or small results.

Mortality rate.

Total deaths over the first five years were: up to 1955, 0·8% ; to 1956, 2·0% ; to 1957, 8·2% ; to 1958, 10·2% ; to 1959, 12·1%.

The highest death rate followed the season in which black spot was most severe. All deaths were confined to 5 of the 8 scions : Ena Harkness (2 plants), Emma Wright (3 plants), Lamplighter (5 plants), McGredy's Yellow (10 plants) and Mrs. Sam McGredy (11 plants). All 8 rootstocks were involved, without any significant differences between them. There is thus no evidence so far to support the popular view that certain rootstocks (e.g. *multiflora*) are shorter lived than others. Provided the union is fully compatible, scion vigour alone determines the life of the combined plant.

Longevity, because of its considerable practical importance, is being made the subject of further study.

Flowering season.

The lengths and dates of flowering seasons were plotted after the method of Lenander (1956), taking the key dates as those by which $\frac{1}{4}$ and $\frac{3}{4}$ of the annual flower total had been produced. Differences showed up according to rootstock and scion variety and type of growing season. A typical year is shown in Fig. 2, where totals for all 8 scions have been added together. It will be evident that Pollmeriana, Schmidt's Ideal and *multiflora* gave a 22-29% longer blooming season than Brog's or Pfander's.

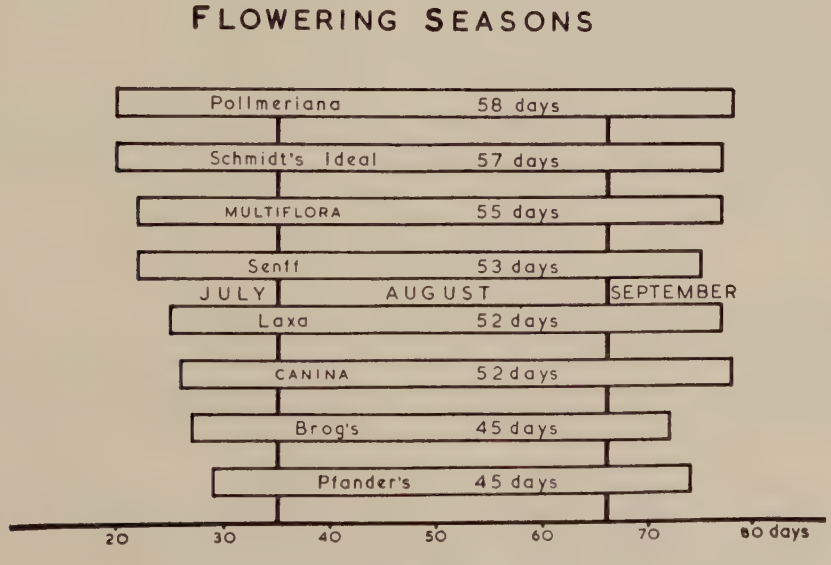

Fig. 2.

Lengths of flowering season for different rootstocks, based on the means for all 8 scions from the dates of $\frac{1}{4}$ to $\frac{3}{4}$ total annual output.

Suckering.

Sucker counts made in 1958 and 1959 are shown collectively in Table II.

TABLE II.

Total suckers for 4 plants of each scion/stock combination, 1958 + 1959.

Rootstock	Peace	Comtesse Vandal	Emma Wright	Ena Harkness	Lamplighter	McGredy's Yellow	Mrs. Sam McGredy	Talisman	Totals for stocks
Pfander's ..	1	9	14	0	0	2	0	5	31
Rosa canina, wild	19	0	18	0	2	0	6	1	46
Brog's ..	24	0	0	12	0	0	12	3	51
Pollmeriana ..	6	0	3	0	5	3	0	0	17
Schmidt's Ideal	36	0	0	6	0	3	1	13	59
Senff	28	5	5	16	0	0	13	3	70
Laxa	5	0	0	0	0	0	0	0	5
Rosa multiflora	1	0	0	0	0	0	0	0	1
Totals for scions	120	14	40	34	7	8	32	25	280

Average per plant, 0·55.

Of the many factors influencing rootstock suckering, three are examined in order of decreasing importance :

Rootstock variety. From Table II, *multiflora* and Laxa can be described as substantially non-suckering.

Scion vigour. Table III shows that there is a close linear relationship between size of bush and the number of suckers growing out from any rootstock on which it is worked. Thus Peace, an outsize bush variety, induces proportionately more suckers than the smaller Hybrid Teas.

TABLE III.

Comparison of scion weight (gm.) and sucker totals from stocks, 1958 + 1959.

Scion	Weight	Number of suckers
Lamplighter	164	7
Emma Wright ..	171	40
McGredy's Yellow ..	215	8
Mrs. Sam McGredy ..	222	32
Comtesse Vandal ..	284	14
Talisman	344	25
Ena Harkness ..	392	34
Peace	1,043	120

Two exceptions to this rule are Emma Wright and Mrs. Sam McGredy. Both throw more suckers than their size would lead one to expect. Perhaps this may be interpreted as the expression of some mild form of stock/scion incompatibility.

Season. The total of suckers for 1959, a hot dry year, was only 69% of that for 1958, a very wet season. All 6 suckering rootstocks showed some decrease (Table IV) and this was most marked in Pfander's.

TABLE IV.

Comparison of suckering on 8 rootstocks in wet and dry seasons.

Rootstock	Number of suckers	
	1958 (wet)	1959 (dry)
Laxa	0	5
Rosa multiflora ..	1	0
Pollmeriana	9	8
Rosa canina, wild ..	24	22
Pfander's	27	4
Brog's	32	19
Schmidt's Ideal ..	33	26
Senff	40	30

Flower quality.

Attempts were made to match flowers in the field against a selected "standard bloom", and to arrange cut samples in order of quality. Although sufficient blooms at comparable stages of development were not available for the results to have statistical value, there was evidence that differences associated with the general vigour effect (i.e. petal size and texture) do exist and recur year after year. An adequate study of flower quality could be undertaken only under nursery conditions with large numbers of plants of each stock/scion combination. It is important that this should be done, since a mere assessment of flower number gives only a partial picture of the practical worth of vigorous and non-vigorous rootstocks.

Frost damage.

When severe frosts were experienced in late spring, scions on *multiflora* roots suffered significantly more die-back than those on any of the other 7 roots. It will be recalled that plants on *multiflora* are the tallest and most exposed and many growers have commented on its long growing season, which may account for the extent of frost damage.

Susceptibility to diseases and pests.

Incidence of black spot, mildew and other infections was scored in the field and found to be purely varietal—that is, determined by the scion and unaffected by choice of rootstock.

DISCUSSION.

Findings so far are largely in agreement with those obtained between 1948 and 1955 in Sweden by S.-E. Lenander (1956), using a large number of scion varieties but only 3 rootstocks : *Rosa canina, R. multiflora* and *R. rugosa* Hollandica.

Several instances have been demonstrated of the root system influencing the scion in garden roses. The effect is generally one of vigour in the rootstock, a strong grower tending to produce taller plants, heavier canes, more branches and more (but not necessarily better) flowers. Strong differences exist between the scion varieties, and their growth pattern may be intensified or diminished but never overruled by the choice of roots. Thus Peace, by nature a large shrub, increases in size and flowering capacity steadily over the years. Although the rootstock alters the seasonal response and overall yields, the strongly rising growth curve remains very unlike the level graph of, say, Emma Wright, a less robust rose.

A closer study of this vigour effect reveals a point of considerable practical importance. The high yield on *multiflora* roots is achieved by the growth of lateral buds which would otherwise have remained dormant. Peace gives a very clear demonstration of this effect (Fig. 3). Blooms are characteristically solitary, at the end of long, straight canes. Peace on *multiflora* roots, however, tends to form sprays of rather smaller blooms giving the plant more of the characters of a Floribunda rose. In favourable years the effect is so marked that isolated plants on *multiflora* roots can be picked out visually in the randomized blocks. Inflorescence size and form is an important character in classifying the Groups of *Rosa*, and no less so in garden roses where the utility of a variety depends on its flower size, arrangement, and length of cutting stem. Among the wild ancestors of garden roses, *R. gallica* and *foetida* have large flowers borne singly or in clusters of up to 3, whereas *moschata* and *multiflora* are climbers with small blooms in sizeable clusters. Their descendants in gardens have been selected for many combinations of flower size and grouping, as shown in Table V.

TABLE V.

Rose Groups in relation to floral characteristics.

Inflorescence type	Flower size		
	Small	Medium	Large
Large trusses ..	Polyanthas Wichuraianas	Hybrid Musks	—
Small trusses ..	Banksians	Floribundas Chinas	Grandifloras
Solitary	—	Shrub and Old-fashioned Roses	Hybrid Perpetuals Hybrid Teas

It follows that a rootstock which tends to alter the flower size/number ratio, the grouping or the length of free stem, could not fail to be of interest to the rose grower. Long, clean, cutting stems are essential for exhibition roses and those used for home decoration. The exhibitor naturally puts flower quality first, irrespective of the number of blooms produced. On the other hand, displays of massed colour in the flower border call for as many blooms as possible, without regard for their size, individual

PLATE I.

Fig. 3.

Canes of Peace showing different types of habit and length of flower stalk. The centre type of growth is typical of rootstocks of medium vigour (most *canina* strains). Rootstocks of low vigour (as Laxa) often have solitary blooms (right). Only the very vigorous *multiflora* rootstock produces the degree of branching seen on the left.

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perfection or length of stalk. Here, clearly, we have two opposite extremes which can best be met by the use of separate rootstocks selected towards one or the other. It is possible, of course, that pruning or thinning a vigorous plant would give fewer, better flowers, but it still seems obvious that the many different uses of the rose call for a selection of different rootstock varieties rather than the impossible quest for one good all-rounder. If nurserymen do not at first take kindly to the extra complication, they might be reminded of the acknowledged value of a choice of root systems in other important crops, notably apples and pears.

Considerably wider trials will be needed before general answers can be given on rootstock performance : these results were, as has already been pointed out, from a pilot experiment designed to investigate the reality of rootstock effect in roses. The remarkable performance recorded here for *multiflora* with 8 Hybrid Teas may not be matched elsewhere with different scions, different soils or even different strains of *multiflora*, of which many exist. A second trial laid out in 1957 with a more varied range of scions and strongly contrasted soil types already shows a somewhat different pattern of rootstock behaviour. In England, at least, *multiflora* is a much less popular rootstock than *canina* in its many strains. The reasons most often advanced are the short neck and thin bark for budding, the long growing season with consequent late dormancy leading to losses in transit and frost damage. If, however, it can be established that *multiflora* consistently produces outstandingly vigorous scions, then there is a case for meeting these drawbacks by selective breeding or modified nursery techniques.

SUMMARY.

1. A pilot experiment was undertaken to ascertain the nature, if any, of rootstock action on 8 Hybrid Tea garden roses.

2. Positive effects were established for plant size, flower total and flowering season, as well as for degree of suckering. Frost damage was found to be most severe on the largest plants. *Rosa multiflora* gave the best all-round performance.

3. Longevity and susceptibility to pests and diseases were found to be varietal characters of the scions and were unaffected by choice of roots.

4. Secondary effects of a vigorous root system were noted in the tendency to force out dormant buds and form trusses of several, short-stalked, medium blooms instead of large solitary ones. The garden utility of a rose—its value for exhibition or mass effect—can thus be influenced by the type of rootstock on which it is raised.

5. It is clear that the search for a single, all-purpose rose rootstock is unrealistic, and that the time has come to recognize separate clonal or true-breeding rootstocks for special purposes, modelling the programme on that already established for fruit rootstocks.

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INDICATOR PLANTS FOR LATENT VIRUS INFECTION IN APPLE

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PREVIOUS workers have reported that several species of *Malus* and *Prunus* developed symptoms after scions from apparently healthy plants of many apple varieties were grafted to them. As different indicator varieties and virus sources were used, the relative merits of the former and the number of distinct viruses concerned have been problematic. Guengerich and Millikan (1956) used Virginia Crab and later (1956 (M. and G.), 1959) *Amelanchier* spp. and Spy 227, to test for the presence of stem-pitting virus, which, as it is carried in many scion varieties, limits the use of Virginia Crab as a hardy interstock (Smith, 1954). Mink and Shay (1959) selected R12740-7A from *Malus pumila* Mill. seedlings of Russian origin as an indicator for the syndrome they named "chlorotic leaf spot". Luckwill and Campbell (1959) showed that a clone of *Malus platycarpa* Rehd. was sensitive to more than one virus prevalent in scion and rootstock varieties. Blodgett and Aichele (1960) found that varieties of *M. purpurea* Rehd. and other species of ornamental crab were severely affected by budding with commercial varieties. Other indicators used to detect latent virus infection in apple were peach (Posnette, 1953), *Amelanchier* spp. (Harris, 1958), *Prunus tomentosa* Thunb. (Welsh and Keane, 1959), *Crataegus crus-galli*, *C. mollis* Scheele, *Malus floribunda* Sieb. (Millikan and Guengerich, 1959) and strawberry (Harris, 1957).

The first evidence of apple rootstock infection with viruses other than those causing mosaic, rubbery wood and chat fruit occurred when peach seedlings developed leaf symptoms after ingrafting* with bark chips from an M.IX rootstock (Posnette, 1953). The symptoms were first attributed to rubbery wood virus with which the M.IX was infected, but identical symptoms developed on peach seedlings ingrafted with Lord Lambourne scions free from rubbery wood, mosaic and chat fruit viruses (Harris, 1957). Subsequently the scions were found to be infected with the stem-pitting virus (Anon, 1959), but the relation of the symptoms on peach to those on *Malus* hosts remained obscure.

Materials and methods.

The plants tested for latent virus infection included two varieties, Golden Delicious and Lord Lambourne, already known from tests on Virginia Crab to be carrying stem-pitting virus, and the American Early Harvest known to be free from this virus. Scions of Golden Delicious and Early Harvest were obtained from the National Fruit Trials, Brogdale, Kent. The tested Malling (M.), and Malling-Merton (MM.) rootstocks were propagated from stools previously found free from rubbery wood and mosaic viruses (Posnette and Cropley, 1954).

Virus tests with the Long Ashton clone of *M. platycarpa* as an indicator were done by double-budding in July, either on seedling rootstocks at Long Ashton Research

* *To ingraft*: a verb used here to describe the method of inoculation whereby a virus is transmitted from one plant to another by grafting.

Station (through the collaboration of Dr. L. C. Luckwill and Mr. A. I. Campbell) or on MM.104 stocks at East Malling. Most of the plants were also indexed on Spy 227, Virginia Crab and R12740-7A by double-budding on MM.104 stocks, one third of which were single-budded with each indicator as controls. The tests with 3-month-old Elberta peach seedlings were made by chip-grafting in a glasshouse during May and June ; the seedlings were cut back so as to leave two buds above the inoculation point.

RESULTS.

The results for all five indicator plants are assembled in Table I.

Malus platycarpa.

The symptoms caused by the viruses latent in certain apple clones were grouped by Luckwill and Campbell (1959) into three categories : line pattern, scaly bark and stunt. In tests now described, all these symptoms developed on plants infected with viruses from Lord Lambourne, M.IV, M.VII, M.IX, M.XXV and MM.109* (Group 1). Golden Delicious inoculum did not stunt the test plants, but the symptoms induced were otherwise identical with those caused by clones in Group 1. Plants ingrafted with Early Harvest, M.II and MM.106/3 (Group 2) developed line pattern only. Grafting with buds of M.XII, M.XVI, M.26, MM.104, MM.106/1, MM.106/2, MM.111 and Crab C (Group 3) induced no symptoms on the test plants.

Spy 227.

Chlorotic rings and lines (Fig. 1), similar to those on *M. platycarpa*, developed on the leaves during the summer following ingrafting with all the clones in Groups 1 and 2 above. Plants infected with viruses from Group 1 clones developed also leaf epinasty and were stunted from June onwards (Fig. 2) ; by September, splits and necrotic areas had formed in the bark, and pits in the wood (Fig. 3). After one year's growth these stunted plants were less than a quarter the height of the controls and of the plants budded with clones in Groups 2 and 3.

Russian clone R12740-7A.

The first leaves to develop on infected plants were small and puckered, with chlorotic spots and rings as described for the chlorotic leaf spot syndrome (Mink and Shay, 1959). Some of the scions infected with virus from Group 1 clones died in a few weeks and none grew more than 3 cm. during the year. Those infected with virus from Group 2 clones were only slightly less affected, whereas the controls and the plants ingrafted with Group 3 clones were symptomless and grew to an average height of 120 cm.

Virginia Crab.

Two patches of bark, each about 8 sq. cm., were peeled from the base of each Crab stem 2 years after budding so that the xylem could be examined for pits. Also one indicator plant ingrafted with each clone was cut 9 cm. above the union, soaked in water overnight, and all the bark removed. The extent of xylem pitting varied

* Except where indicated, e.g. MM.106/1 and MM.106/3, all subclones behaved alike.

TABLE I.

Results of inoculations on 5 virus indicator varieties.

Source	Indicator							
	Clone R12740-7A	*M. platycarpa*			Spy 227		Virginia Crab	Peach
	Leaf spot; stunt	Line pattern	Scaly bark	Dwarf	Line pattern	Epinasty, dwarf, bark necrosis, xylem pits	Xylem pits	Green mottle
Group 1								
Lord Lambourne ..	+	+	+	+	+	+	+	+
M.IVb*	+	+	+	+	–	–	+	–
M.IVf	+	+	+	+	–	–	O	O
M.VIIa	+	+	+	+	–	–	+	+
M.IXa	+	+	+	+	+	+	+	O
M.XXV/2	+	+	+	+	+	+	O	–
M.XXV/3	–	+	+	+	+	+	–	–
M.XXV/4	–	+	+	+	+	+	–	–
MM.109/1	+	+	+	+	+	+	+	+
MM.109/2	–	+	+	+	+	+	–	–
MM.109/3	–	+	+	+	+	+	–	–
Golden Delicious ..	+	+	+	O	+	+	+	–
Group 2								
Early Harvest ..	+	+	O	O	+	O	O	–
M.IIa	+	+	O	O	+	O	O	O
MM.106/3	+	+	O	O	+	O	–	–
Group 3 M.XIIa, M.XVIa M.26/1, MM.104/1 MM.104/2, MM.104/3 MM.106/1, MM.106/2 MM.111/1, Crab C/a	O	O	O	O	O	O	O	O

* Suffixes a, b, 1, 2, etc., indicate particular subclones of M. and MM. rootstocks tested on all indicators.

+, symptoms present; O, no symptoms; –, not tested.

even within a set of plants ingrafted with the same source, and it appeared that two years was not long enough for the full development of this symptom. Nevertheless, pits occurred in some plants of most sets ingrafted with Group 1 clones (Fig. 4), but not in any others. Virginia Crab trees infected with stem-pitting virus in earlier tests have produced small misshapen fruit (Fig. 5), but the plants in the present tests have not yet fruited.

PLATE I.

Fig. 1.
Leaf symptoms on Spy 227 with virus from MM.106/3.

Fig. 2.
Spy 227 on MM.104 with infective bud from M.XXV/4 (*left*) and non-infective bud from M.26/1 (*right*).

Fig. 3.
Spy 227 with virus infection from M.XXV/3. *Left:* bark necrosis and splitting. *Right:* bark removed to expose pits in xylem.

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FIG. 5.
Virginia Crab fruit from control tree (*above*) and tree budded with Golden Delicious (*below*).

FIG. 4. *Left.*
Xylem pitting on Virginia Crab budded with Lord Lambourne.

FIG. 6.
Elberta peach seedling leaves: *upper*, control; *centre*, dark green sunken mottle; *lower*, purple pattern after chip-budding with Lord Lambourne.

Peach seedlings.

Fifteen Lord Lambourne trees propagated from five different scion sources, by grafting on clonal and seedling rootstocks, were indexed by chip-budding on Elberta peach seedlings. Thirteen of these Lord Lambourne trees were infected with a virus that caused a green mottle on peach leaves. The dark green areas were depressed in the upper surface of the leaf (Fig. 6) and tended to be iridescent, with purple coloration developing in late summer. In the second year after inoculation, the mottle was usually accompanied by faint yellow or purple ring-and-line patterns on leaves borne close to the main stem. This virus, or one causing identical symptoms, is prevalent in plum (Ellenberger, 1960) and cherry (Posnette, 1954), but is distinct from the plum line-pattern or apple mosaic virus.

The peach green mottle virus was transmitted directly from one M.IX rootstock (Posnette, 1953), but apparently was not present in the M.IXa clone indexed in the present tests.* The virus occurred in two of the Group 1 clones (M.VII and MM.109) but, in view of the uncertain graft union between apple and peach, negative results with other clones are perhaps not conclusive.

DISCUSSION.

These results suggest that the Group 2 clones (M.II, MM.106/3 and Early Harvest) were infected with one virus, chlorotic leaf spot, which causes only leaf symptoms in *M. platycarpa* and Spy 227, and also stunts R12740-7A so severely that the effects of other viruses are obscured. Some of the Group 1 clones were infected with the stem-pitting virus that affects Virginia Crab, but although two of them (M.IVf and M.XXV) apparently did not contain this virus, they all produced severe symptoms on *M. platycarpa* and Spy 227. If the ability to pit Virginia Crab is regarded as diagnostic of stem-pitting virus, either a distinct strain or another virus was responsible for the epinasty and pitting on Spy 227 and dwarfing of *M. platycarpa*. Of the latter indicators, Spy 227 is preferred because it shows leaf epinasty early in the summer and also develops necrosis and pitting more severely than *M. platycarpa*.

The identity of the virus that caused the green mottle in peach is uncertain ; it was detected only in sources with stem-pitting virus, but it was apparently not present in M.IXa,* which induced symptoms on all the *Malus* indicator clones.

The prevalence of these latent infections requires a reinterpretation of previous reports of the transmission of apple viruses to other genera. For example, the symptoms that developed on quince seedlings after inoculation with apple mosaic virus (Posnette, 1957) may well have been due to viruses latent in the apple scions.

The presence of chlorotic leaf spot virus in plants of M.II and of both this and the stem-pitting virus in M.VII was reported in the U.S.A. (Mink and Shay, 1959) and our results with different sources of these clones are in agreement. The distribution of latent infection in Malling and Malling-Merton rootstocks in Canada also is very similar (M. F. Welsh, personal communication). In countries where clonal rootstocks are widely used, most scion varieties must have become infected and only tolerant clones have been selected for commercial use as rootstocks or scions.

Weeks (1948) reported that the " incompatibility " of certain American scion varieties with Spy 227 rootstock differed from other cases of stock-scion incompatibility in two ways : the rootstock died, and the " compatible " varieties were rendered

* Recent tests have shown that the peach green mottle virus is present in M.IXa.

lethal to Spy 227 by budding with an " incompatible " variety. This was the first evidence of latent virus infection in apple, although nurserymen have long known that the dwarf and semi-dwarf Malling stocks were unsuitable for many varieties of ornamental *Malus* spp. The reason is now apparent.

Virus infection of three clonal rootstocks (M.XXV, MM.106 and MM.109) raised from seed in 1930 and released for commercial propagation only a few years ago may indicate that the viruses are spread by vectors. It should be noted, however, that the infection of M.XXV and MM.109 with both chlorotic leaf spot and Spy 227 epinasty viruses, and of MM.109 also with stem-pitting virus, may be explained by the fact that the original seedlings were grafted with scions of Lane's Prince Albert on the stools (Tydeman, 1940). No record has been found of similar grafting on M.26, MM.104, MM.106, and MM.111, and the means by which MM.106/3 became infected with chlorotic leaf spot virus is unknown. The absence of these viruses from M.XIIa, M.XVIa and Crab C/a, clones which have been propagated for many years in stoolbeds adjacent to those of infected clones of the Malling series, indicates that vectors are either rare or inefficient.

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SUMMARY.

A range of Malling and Malling-Merton apple rootstocks and three scion varieties were tested for latent virus infection by using five indicator hosts. The clones fell into three groups according to the effect of their virus content on Spy 227 and *Malus platycarpa*. One group caused symptoms on leaves, bark and xylem, the second caused only leaf symptoms. The clones that affected these indicators also produced chlorotic leaf spot on the variety R12740-7A of Russian origin. Some of the clones in the first group induced stem-pitting on Virginia Crab and green mottle on peach seedlings ; these hosts probably indicated viruses distinct from those affecting Spy 227 and R 12740-7A.

The prevalence of latent virus infection in commercial scion and rootstock varieties has resulted in unconscious selection for tolerance, and accounts for the unsuitability of some clonal stocks for ornamental species now known to be sensitive.

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AUTUMN-FRUITING IN RASPBERRIES

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RASPBERRIES are those species of *Rubus* included in the subgenus *Idaeobatus* ; they normally fruit on biennial canes arising from a persistent rootstock. Two species are widely grown—the red raspberry, *R. idaeus* L. and its subspecies *strigosus* (Michx.) Maxim., and the black raspberry, *R. occidentalis* L. The former is grown throughout the temperate zones whereas the black raspberry and its hybrid with the red, the purple cane hybrid, are grown principally in N. America. In cultivated red raspberries the terminal and axillary buds formed on the one-year-old canes normally remain dormant in the first year, forming fruiting branches (laterals) the following spring and summer, and the canes dying back in the autumn.

REVIEW OF LITERATURE ON AUTUMN-FRUITING IN *RUBUS*.

Autumn-fruiting, everbearing or tip-fruiting varieties have been known for many years. Such varieties flower and fruit on the tips of one-year-old canes late in the season ; the tip dies after bearing its crop so that only the lower part of the cane remains to fruit in the following summer. The autumn-fruiting character appears in red, black and purple raspberries. Hedrick (1925) describes Ohio Everbearing, an autumn-fruiting black raspberry which was introduced in 1832, and quotes Mawe and Abercrombie who recorded a " twice-bearing " red raspberry in 1778. More recently, Scott and Darrow (1954) describe Purple Autumn as the first purple-fruited fall-bearing raspberry to be introduced.

Raspberries are grown commercially for their summer crop, the main demand for autumn-fruiting types coming from private gardeners. However, one of the most widely grown English varieties, Lloyd George, is well known for its autumn-fruiting habit and in favourable seasons will produce a fair second crop. Many other old autumn-fruiting varieties are known (Barker and Spinks, 1919 ; Crane, 1935 ; Lewis, 1941) ; more recently there have been deliberate attempts to breed for this character, particularly in North America. This work has led to the introduction of a number of varieties such as Indian Summer, Durham and September, which will usually ripen their second crop well before the frosts (Slate, 1938, 1951 ; Yeager and Richards, 1948).

The annual-flowering tendency in Rubus.

The genus *Rubus* includes herbaceous as well as perennial and biennial caned species; these differences in fruiting habit have been used by systematists in delimiting the subgenera. The herbaceous species (about 28 in all) comprise five of the subgenera; in these, annual flowering is obligatory if sexual reproduction is to occur at all. Species of this type that have been cultivated, or used in breeding, include *R. arcticus* L., *R. chamaemorus* L. and *R. saxatilis* L.

In the subgenus *Idaeobatus*, *R. illecebrosus* Focke, the strawberry raspberry, is exceptional in that it flowers annually on the tips of short canes. In *R. idaeus*, the

existence of numerous autumn-fruiting cultivated varieties has already been mentioned, several of them being polyploids (Moffett, 1930 ; Lewis, 1941). The autumn-fruiting character is also found in the wild. Thus Slate (1948) has described early autumn-fruiting selections from the wild North American form *R. idaeus strigosus*, and Haskell (1960) found that five out of 20 progenies raised from seed collected from wild raspberries (*R. idaeus*) in Great Britain were segregating for this character, although none of the parent plants was tip-fruiting. Hedrick (1925) lists several varieties of autumn-fruiting black raspberries (*R. occidentalis*), most of which were apparently selections from the wild.

There appears to be no mention in the literature of autumn-fruiting in perennial caned species, but at East Malling one plant of *R. odoratus* L. (subgenus *Anoplobatus*) regularly flowers and fruits on the tips of one-year-old canes.

Flower initiation and autumn-fruiting.

Workers in both America (MacDaniels, 1922 ; Waldo, 1934, 1935 ; Snyder, 1936) and Great Britain (Mathers, 1952 ; Wood and Robertson, 1957 ; Robertson, 1957 ; Williams, 1959b) have investigated inflorescence development and flower initiation in the red raspberry. These workers have shown that in axillary buds an inflorescence axis with several flower primordia is usually laid down in autumn, although MacDaniels, working in New York State, found only partial differentiation in early January, and Snyder in Iowa did not find flower initials until April. Much less is known about initiation in terminal buds. Waldo (1934) found that, in Oregon, flower initiation in autumn-fruiting varieties such as Ranere and Lloyd George began as soon as shoot elongation ceased in summer. In 1933, Lloyd George stopped growing about 15th July and fruit-bud formation developed rapidly, in basipetal succession.

In the East Midlands of England, Williams (1959b) showed that flower initials were evident in terminals of Lloyd George in late July, and that initiation had occurred in all terminals after the third week in August. The shoots in which flower initiation occurred earliest were still elongating and Williams considers that they would probably have developed autumn flowers, whereas terminal buds in which initiation occurred later had ceased elongation and were becoming dormant. The first axillary primordia in Lloyd George were found in the 5th to 15th buds below the terminal in the fourth week of August and thereafter initiation occurred progressively downwards, only a few buds at the base of the shoot remaining vegetative. In the non-autumn-fruiting variety Malling Promise, Williams found the first flower initials in both terminal and axillary buds in the second week in September, after shoot elongation had ceased. The earliest axillary buds were those in the region 5 to 10 buds below the apex.

Genetics of autumn-fruiting.

In a brief summary of a paper by Lewis (1941) it is stated that autumn-fruiting in red raspberries is due to a recessive gene but, in a personal communication (1960), Lewis regards this as an over-simplified picture and considers that there was variation in expression of the character which indicated that other genes with minor effect may be involved. Haskell (1960) assigns the symbol "af" to a single recessive gene controlling tip-fruiting, on the basis of ratios of approximately 3:1 obtained in two progenies, each of 50 plants, derived from open-pollinated seed collected from wild raspberries in Scotland. In this connexion, however, it should be noted that vicinism is not

uncommon in the red raspberry. Several other workers have reported percentages of tip-fruiting seedlings in progenies segregating for the character. In no case do their results bear out the theory of control by a single recessive gene. In crosses between Alexandra Autumnal and Bath's Perfection, Harzuweil, and Schaffer's Colossal, about 10% of autumn fruiters were obtained (Barker and Spinks, 1919). In twelve crosses between tip-fruiting derivatives of Lloyd George, Slate and Suit (1944) obtained from 17% to 57% tip-fruiting seedlings, and in selfed progenies from the same material the percentages ranged from 8 to 86. As the authors point out, these results are obviously not compatible with the theory of a single recessive gene. Waldo and Darrow (1941) found little tendency to fall-bearing in selfed selections of Newburgh × Lloyd George and of Chief × Lloyd George. Tip-fruiting Lloyd George derivatives crossed with Ranere (an early autumn-fruiting variety of American origin) gave 13-44% of tip-fruiting segregates (Slate and Suit, 1944), whereas crosses between September ((Lloyd George × Newman) × Ranere) and two autumn-fruiting selections of *R. idaeus strigosus* gave 88 and 89% of tip-fruiting plants in the F_1's (Slate, 1948). In Virginia, crosses between autumn-fruiting Lloyd George derivatives and Ranere or its seedling Sunrise gave autumn-fruiting percentages of from 21 to 93, while F_1's of Sunrise crossed with the non-autumn-fruiting varieties Latham, Newburgh and Chief gave 4 to 6% (Oberle *et al.*, 1949 ; Oberle and Moore, 1952). Crosses between non-tip-fruiting black raspberries and autumn-fruiting red raspberries gave from 46 to 57% autumn-fruiting progeny (Oberle and Moore, 1952). Slate (1939) and Waldo and Darrow (1941) emphasize the effect of environment on the expression of the autumn-fruiting character and consider it to be under complex genetic control.

RESULTS.

The data here presented have been obtained largely from progenies bred for characteristics other than autumn-fruiting, in the course of a programme of breeding for characters of economic importance. Scarcity of space and labour severely limited progeny size and necessitated a system of early culling of all but the more promising material. Although purely genetical considerations have often had to take second place, the evidence obtained proves conclusively that autumn-fruiting is under complex genetic control.

Throughout this paper, the terms autumn- and tip-fruiting have been used to include canes or plants showing terminal flower-buds, flowers or fruits, since all such plants should be able to produce autumn fruit under suitable environmental conditions.

Autumn-fruiting in Lloyd George and its derivatives.

Lloyd George S_1.

S_1 seedlings of Lloyd George (Family 115) were planted in 1955 and recorded yearly for autumn-fruiting from 1956 to 1958. Records were made at the end of the growing season in October, at which time it is possible to distinguish even the most minute exposed flower buds in the tips of the canes. Plants in which at least one well-grown cane was showing flower buds, however small, or open flowers or fruits, were recorded as autumn-fruiting (Table I). A continuous range in season of autumn crop was found from those ripening most or all of their crop in September to those just showing a few flower buds at the end of the growing season.

TABLE I.

Autumn-fruiting in Lloyd George S_1.

Total		Cumulative percentages of autumn-fruiting		
Autumn-fruiting	Not autumn-fruiting	1956	1957	1958
200	2	68·8	97·5	99·0

Table I shows that 2 out of 202 seedlings did not tip-fruit during 1956-58. One of these two seedlings was discarded after the 1958 record but the second was retained, and failed to tip-fruit in both 1959 and 1960. This seedling was in every other way characteristic of the family and, although not vigorous, was no weaker than many seedlings recorded as autumn-fruiting. After five years' records it seems fair to assume that this plant was not capable of tip-fruiting in the particular environment in which it was growing. The other non-tip-fruiting seedling, discarded in 1958, can fairly be classified as non-tip-fruiting, since the vast majority of seedlings in this family produced their first autumn flowers in 1956 or 1957, only three of them (1·5%) not doing so until 1958.

Lloyd George S_2.

Selfed progenies from tip-fruiting seedlings in Family 115, selected in the main for their capacity to produce early or good-quality autumn fruit, were recorded for autumn-fruiting in their second and third years from planting (Table II).

TABLE II.

Autumn-fruiting in Lloyd George S_2.

Family	Parentage	Total		Percentage autumn-fruiting	Parental order of autumn-fruiting
		Autumn-fruiting	Not autumn-fruiting		
291	115/70 self	8	0	100	1
297	115/177 self	42	1	97·7	3
249+296	115/166 self	31	1	96·9	2
293	115/103 self	12	5	70·6	5
295	115/148 self	10	5	66·7	6
289	115/45 self	14	7	66·7	4
298	115/223 self	2	15	11·8	7
Total		119	34		

It is evident that these S_2 seedlings differ considerably in their genetic composition regarding autumn-fruiting and that control of the character in Lloyd George is more complex than is suggested by Haskell (1960) for wild *R. idaeus* selections.

The last column in Table II gives the approximate average order of autumn-fruiting in the parent plants. Within the bracketed groups, the exact order of flowering altered slightly from year to year, but there was no overlap between the two groups.

It is evident that there is a correlation between *season* of tip-fruiting in the parent and *percentage* tip-fruiting in the progeny.

Lloyd George S_1 × non-autumn-fruiting varieties.

In 1958 and 1959 five families were raised from crosses between tip-fruiting Lloyd George S_1 seedlings and non-autumn-fruiting types. These latter comprised : two seedlings of an inbred parent line (P_1), which breeds true for absence of tip-fruiting ; Malling Promise, which also breeds true in its S_1 generation (Grubb, personal communication) ; 155/4, which carries 75% of P_1 " blood " and 25% of Landmark ; and 129/89, a non-autumn-fruiting selection from a segregating S_2 of Burnetholm. Although Landmark is not an autumn-fruiting variety, a low proportion of tip-fruiting types appeared in its S_1 generation. On selfing, 129/89 gave 10·0% tip-fruiting seedlings (Table V). Table III gives the segregations for autumn-fruiting in these five families.

TABLE III.

Autumn-fruiting in Lloyd George S_1 × non-autumn-fruiting varieties.

Family	Parentage	Total		Cumulative percentages of autumn-fruiting	
		Autumn-fruiting	Not autumn-fruiting	1959	1960
459	129/89 × 115/166	16	2	—	88·9
356	P_1 × 115/166	12	18	20·0	40·0
351	P_1 × 115/41	8	16	20·8	33·3
465	Promise × 115/45	6	42	—	12·5
411	115/45 × 155/4	1	19	—	5·0

It is probable that records in 1961 will show a considerable increase in the percentages of autumn-fruiting seedlings in the two-year-old families 459, 465, and 411. Results from families 351, 356, and 465 show that Lloyd George derivatives can transmit autumn-fruiting in crosses with varieties known to breed true for its absence, and confirm that the character is not controlled by a single recessive gene.

Lloyd George S_1 × autumn-fruiting varieties.

Four families derived from crossing autumn-fruiting Lloyd George selfs with autumn-fruiting seedlings containing no Lloyd George " blood " were examined for autumn-fruiting in 1960 (Table IV). Of the other parents involved, L 518 is a very early tip-fruiting selection from wild *R. idaeus strigosus* kindly supplied by Dr. G. L. Slate of Geneva, New York ; 130/31 is a tip-fruiting S_1 seedling of Baumforth A ; 145/13 is an autumn-fruiting black raspberry again supplied by Dr. Slate ; 129/91 is a very late tip-fruiting selection from the S_2 of Burnetholm.

It is of interest here to contrast the autumn-fruiting percentage in Family 332 with that in Family 459 (Table III). Both are crosses between seedlings of Families 129 and 115 but Family 332, very late × late, gave 0·0% autumn-fruiting after three years whereas Family 459, non-tip-fruiting × early, gave 88·9% autumn-fruiting after only two years of growth. Although progenies are small, these facts again

TABLE IV.

Autumn-fruiting in Lloyd George S_1 × unrelated autumn-fruiting seedlings.

Family	Parentage	Parental season of autumn-fruiting	Total		Percentage autumn-fruiting
			Autumn-fruiting	Not autumn-fruiting	
409	115/177 × L 518	early × very early	34	0	100·0
358	130/31 × 115/70	late × early	2	0	100·0
445	145/13 × 115/223	early × very late	12	0	100·0
332	129/91 × 115/123	very late × late	0	5	0·0

suggest that earliness of autumn-fruiting in the parent and percentage transmission to the progeny are correlated.

AUTUMN-FRUITING IN BURNETHOLM AND ITS DERIVATIVES.

Burnetholm S_1, S_2 and S_3.

Both the Scottish raspberry variety Burnetholm and a selfed seedling from it, AR1, bred by Mr. R. D. Reid of Auchincruive, can produce flowers late in the season at East Malling, usually too late to ripen a crop. Eight seedlings in a selfed progeny from AR1 (Family 129), raised in 1955, were retained until 1960, long enough to establish their autumn-fruiting status with complete certainty. Six were tip-fruiting and two were not. Selfed progenies of three of the tip-fruiting seedlings (Families 318, 319, 321) and of two of the non-tip-fruiting seedlings (Families 323, 324) were raised in 1958 and recorded for autumn-fruiting in October 1960 (Table V). In addition, records were made on Families 320 and 322 ; the parents of these were not retained long enough to ascertain their autumn-fruiting status.

TABLE V.

Autumn-fruiting in Burnetholm S_3 progenies.

Family	Parentage	Parental order of autumn-fruiting	Total		Percentage autumn-fruiting
			Autumn-fruiting	Not autumn-fruiting	
318	129/5 self	1	17	3	85·0
319	129/30 self	2	12	5	70·6
320	129/39 self	?	6	6	50·0
321	129/60 self	3	3	10	23·1
322	129/74 self	?	1	6	14·3
324	129/89 self	Nil	2	18	10·0
323	129/80 self	Nil	1	14	6·7

Percentages of tip-fruiting seedlings from known tip-fruiting parents ranged from 23·1 to 85·0, while 10% and 6·7% tip-fruiting progeny were obtained from non-tip-fruiting parents. It is evident that in Burnetholm, as in Lloyd George, autumn-fruiting is a complex character. Even in these small progenies, the range in

autumn-fruiting percentages and the correlation between these and the parental order of autumn-fruiting are strongly suggestive of minor-gene control of the character.

Burnetholm S_2 × non-autumn-fruiting varieties.

Two small families with the late tip-flowering Burnetholm S_2 seedling 129/91 as female parent were raised in 1958. The male parent of one of these was P_1, which, as already stated, breeds true for absence of autumn-fruiting ; that of the other was a seedling of an inbred line (P_3) of Norfolk Giant parentage which has little tendency to tip-fruiting, as will be shown later. None of the F_1 seedlings (10, × P_1 ; 7, × P_3) tip-fruited in 1960. The results from this P_1 cross contrast sharply with those obtained from the P_1 × 115 hybrids (Table III) where, in two families of the same age as those mentioned above, 33·3% and 40% of autumn-fruiting seedlings were recorded in 1960. It seems likely that the greater earliness of autumn-fruiting in the 115 parents may provide at least a partial explanation of this difference in otherwise strictly comparable F_1's.

Autumn-fruiting in derivatives of L 518.

Clonal material of a plant of *R. idaeus strigosus*, selected by Dr. G. L. Slate for its autumn-fruiting capacity, was received in 1954. This plant, L 518 (Slate's 21289), proved to be very early autumn-fruiting at East Malling, in some seasons ripening most of its fruit in August. In 1957 it was selfed and crossed with 129/80. In the selfed family four plants were retained after selecting for fruit quality in the summer crop. These all proved to be tip-fruiting. In the cross with 129/80 four plants selected in the same way were also tip-fruiting. Four more F_1 families were raised in 1959. Segregations for autumn-fruiting in these are given in Table VI.

Table VI.

Autumn-fruiting in 1960 in F_1's of L 518 × inbred lines and of L 518 × Landmark.

Family	Parentage	Parental season of autumn-fruiting	Total		Percentage autumn-fruiting
			Autumn-fruiting	Not autumn-fruiting	
409	115/177 × L 518	early × very early	34	0	100·0
416	Landmark × L 518	nil × very early	25	21	54·3
408	166/10 × L 518	nil × very early	11	19	36·7
410	121/8 × L 518	nil × very early	23	40	36·5

Of the four maternal parents of these families, 121/8, 166/10 and Landmark do not tip-flower ; 166/10 bred true for absence of autumn-fruiting ; 121/8 (Norfolk Giant $S_2 = P_3$ line) on selfing gave one very late tip-fruiting seedling out of 27 ; Landmark gave a low percentage of tip-fruiting seedlings on selfing ; and 115/177 is an early tip-fruiting S_1 seedling of Lloyd George.

The appearance of tip-fruiting seedlings in Family 408 proves that autumn-fruiting in this wild *R. idaeus strigosus* selection is not controlled by a single recessive gene. Increasingly higher percentages of tip-fruiting progeny with increase in tip-fruiting " potential " of the seed parent indicate that the factors from the European and from the American source behave similarly and are additive or complementary in effect.

DISCUSSION.

Effect of environment on autumn-fruiting.

Several workers, notably Slate (1939), have emphasized the effect of environment on autumn-fruiting. Length of growing season and autumn temperatures have a marked effect on the autumn crop, and climatic conditions may sometimes prevent the expression of the character completely. Thus, in 1960, four three-year-old seedlings, two in each of Families 351 and 356 (Table III), failed to tip-fruit although all four had flowered very late on the tips in 1959. Furthermore, some plants that tip-fruit in one locality may not do so in another. Thus, Waldo and Darrow (1941) found that 80% of seedlings from the cross Lloyd George × Ranere fruited in the autumn in Oregon, but only 58% in Maryland.

Conditions within the plant itself also have a marked effect on autumn-fruiting. At East Malling, seedlings capable of tip-fruiting very rarely do so in their first year and not all show this character in their second year. A considerable proportion do not fruit until the third year and a very few may not do so until their fourth year (Tables I and III). Moreover, the character is very variable in expression *within* the plant, some seedlings flowering at the tip of one cane only, others at the tips of several canes and still others on all canes. This variability is borne out by counts made on mature clonal material (Table VII).

TABLE VII.

Counts of autumn-fruiting canes in clones of autumn-fruiting varieties in 1960.

Variety	Approx. order of autumn-fruiting	No. of canes		Percentage autumn-fruiting canes
		Autumn-fruiting	Not autumn-fruiting	
Durham	2	80	2	97·6
Indian Summer ..	3	44	5	89·8
St. Walfried	4	52	16	89·7
September	1	47	13	78·3
Malling Notable ..	5	48	17	73·8
Seedling K	6	34	34	50·0
AR1	8	15	16	48·4
Royal Scot	9	15	23	39·5
Baumforth A ..	7	8	28	22·2
Radboud	11	5	29	14·7
Enterprise	10	2	28	6·7
Hercules	12	4	71	5·3

Clearly, Haskell's statement (1960) that "autumn flowering is a discrete character and on the same plant either none of the current year's canes have terminal inflorescences or nearly all of them do" does not obtain in the material examined at East Malling.

Slate (1939) found that vigorous plants tip-fruit better and earlier than weak ones. From this it might be argued that inbreeding depression may have affected results given in this paper. This is unlikely since different S_2 families of Lloyd George of similar vigour contained 100% and 11·8% of autumn-fruiting seedlings (Table II), and all the Burnetholm S_3 families were reasonably vigorous (Table V). The P_1 and

P_3 inbred lines have been deliberately selected for vigour, so that the absence of tip-fruiting in these parent lines cannot be attributed to inbreeding depression.

Genetic control of autumn-fruiting.

Both Lloyd George and Reid's AR1 give, on selfing, some non-tip-fruiting seedlings and some which show a range in their season of autumn-fruiting from considerably earlier than their parents to considerably later ; thus, some of the Lloyd George selfs ripened most of their crop by late September, others produced only a few unopened buds by the end of October, and all gradations between these extremes were to be found. AR1 produces its autumn crop a good deal later than Lloyd George, and its derivatives are correspondingly later. In both lines the distinction between the latest autumn-fruiting seedlings and the non-tip-fruiting seedlings is often dependent on the production by the former of one or only a few canes with two or three small flower buds at the tips.

The segregations for autumn-fruiting in S_1 and S_2 progenies of Lloyd George (Tables I and II) show conclusively that the character in this variety is not controlled by a single recessive gene. The S_1 progeny and 6 out of the 7 S_2 progenies from tip-fruiting parents contained non-tip-fruiting seedlings, the percentage of autumn-fruiters in these 6 families ranging from 11·8 to 97·7. It is probable that a more continuous range would have been obtained in S_2 if selection in the S_1 had not been biassed in the direction of early autumn-fruiting.

S_2 and S_3 progenies of Burnetholm (Table V) show a range in autumn-fruiting from 6·7 to 85%. The parents of these families were not selected for autumn-fruiting, consequently the range of expression of the character in the progenies is more continuous than in the Lloyd George S_2's and is strongly suggestive of minor-gene control.

In selfed derivatives of both Lloyd George and Burnetholm, season of autumn-fruiting in the parent and percentage of autumn-fruiting seedlings in the progeny are correlated (Tables II and V) ; the same correlation is suggested by the behaviour of hybrids of L 518 (Table VI). It appears that in all these cases increasing minor-gene content is reflected by greater earliness of tip-fruiting.

The quantitative nature of control of autumn-fruiting is further suggested by its occurrence in occasional seedlings of lines hitherto true-breeding for its absence. Thus, in eight S_3 progenies of Norfolk Giant, one seedling flowered very late on the tip of a single cane in 1960 ; similarly, one seedling out of 45 in the S_2 of Malling Promise produced very late autumn flowers. It is probable that chance selection during inbreeding had built up minor-gene complexes sufficient in both cases to induce autumn-fruiting.

Components of autumn-fruiting.

Season of autumn-fruiting in raspberries has a very wide range, far wider than that of the summer crop. Thus, at East Malling, L 518 has in some years ripened most of its second crop in August, whereas Hercules usually produces at most a few unopened flower buds in October at the end of the growing season. Other varieties provide a more or less continuous range in season between these two extremes. The expression of the autumn-fruiting character is due to two processes, flower initiation in the terminal bud and cane elongation. It is presumably the interaction of these

PLATE I.

Fig. 1.
Autumn-flowering induced by damage to cane.

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two complex developmental processes with each other and with the environment that makes autumn-fruiting such a variable character. The earliest autumn varieties are those in which flower initiation takes place early while canes are still elongating rapidly and when temperatures are subsequently favourable to quick ripening of the fruit. Such varieties would be most likely to express the character in a wide range of environments and in a high percentage of their canes. In very late varieties, such as Hercules, the balance between flower initiation and cessation of growth is far more delicate, the percentage of canes tip-fruiting is much lower (Table VII), and in some seasons autumn-fruiting is suppressed altogether.

Williams (1959a, 1959b, 1960) has shown that both flower initiation and cane elongation in the raspberry are largely controlled by day-length and temperature. He raises the question whether the onset of dormancy is causally connected with the process of flower initiation, or whether the processes are different responses to similar environmental conditions. It is evident that, in the terminal buds of tip-fruiting varieties, dormancy (i.e. cessation of growth) and flower initiation are not so connected. The ready reversal of the order of occurrence of these two processes in canes or whole plants of late tip-fruiting varieties, by either internal or external environment, suggests that their relative order is largely fortuitous ; day-length and temperature conditions favouring cessation of growth will also favour flower initiation in late varieties, and minor fluctuations in these conditions will determine which process occurs first. In non-tip-fruiting varieties a condition resembling true autumn-fruiting is occasionally induced by damage to the cane tip fairly early in the season before flower initials have been laid down. The resultant branches will sometimes flower on the tips late in the season (Fig. 1). Apparently, damage to the original apex can reverse the sequence of cessation of growth followed by flower initiation, so that in these non-autumn-fruiting varieties, also, dormancy is not an essential prelude to flower initiation. It seems likely that most varieties could be induced to tip-fruit by suitable manipulation of the environment, with the possible exception of those in which early cessation of growth is combined with late initiation of flower primordia.

Williams (1960) found that Lloyd George produced terminal inflorescences after about seven months' constant long-day/high-temperature treatment. In these conditions Malling Promise maintained continuous vegetative growth for 19 months, when the experiment was concluded. These facts might suggest that raspberries can be classified into two discrete groups: tip-fruiting types which are day- and temperature-neutral, and late- or non-tip-fruiting varieties which require shorter days and lower temperatures for flower initiation. However, the continuous range in season shown by unrelated autumn-fruiting varieties and by segregating progenies of early and late autumn-fruiting parents, as well as the genetical data presented in this paper, show that there is no qualitative difference between late and early types, and that Lloyd George and similar " day-neutral " varieties merely represent one end of a continuous range of responses to the environment.

SUMMARY.

Raspberries normally fruit on biennial canes, the terminal and axillary buds remaining dormant in the first year and forming fruiting laterals the following spring. Autumn-fruiting varieties, however, flower and fruit on the tips of one-year-old canes late in the season. The character occurs widely in cultivated and wild red (*R. idaeus* L.) and black raspberries (*R. occidentalis* L.), and in their F_1 hybrids.

Autumn-fruiting is under complex genetic control, and season of autumn-fruiting in parent varieties is correlated with percentage of progeny expressing the character. In mature clonal material, the proportion of tip-fruiting canes is correlated with season of autumn-fruiting.

The two main components of autumn-fruiting, flower initiation in the terminal bud and cane elongation, are known to be largely controlled by day-length and temperature. The sequence normal in tip-fruiting varieties, viz. flower initiation followed by cessation of cane growth, may be reversed, particularly in late tip-fruiting types, by fluctuations in climatic conditions or by changes in the internal environment. Consequently, autumn-fruiting is of variable expression and in some seasons may be suppressed altogether. Autumn-fruiting varieties such as Lloyd George, which are able to form flower initials in long days, represent one end of a continuous range of responses to the environment.

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EFFECT OF SOIL MOISTURE ON FROST RESISTANCE OF APPLE BLOSSOM, INCLUDING SOME OBSERVATIONS ON "GHOST" AND "PARACHUTE" BLOSSOMS

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THE degree of frost damage to a plant depends both upon the plant's hardiness and on the severity of frost encountered. Both these factors may be affected by soil moisture.

Many investigators have shown that plants growing in dry soil are less damaged by frost than well watered ones (Angelo *et al.*, 1939 ; Klages, 1926 ; Steel *et al.*, 1935 ; Way, 1954), while some have observed the reverse, or no effects (Klages, 1926 ; Solovieva, 1952).

Low soil moisture usually hardens plants and increases their protoplasmic permeability (Levitt and Scarth, 1936). It reduces the free water content of the tissues, increases the water-retaining ability of the protoplasm (Lebedincev, 1930), and favours starch hydrolysis and increase in sugar content (Magness *et al.*, 1933) and cell sap concentration. In general dry soil conditions favour the processes which in autumn lead to the so-called maturity of tissues in woody plants that determines their winter hardiness during the rest period.

Low soil moisture under certain conditions may, however, lower the frost resistance of plants. Photosynthesis may be decreased owing to closure of stomata (Heinicke and Childers, 1936), and this may lead to weakening of the plants and prevent the full degree of hardiness being achieved (Brierley and Landon, 1954). Dry soil conditions may also facilitate the lethal desiccation of tissues during and after freezing.

Most of the research on the effect of soil moisture upon frost resistance of plants has been done on their winter hardiness. The present study deals with the effects of soil moisture upon frost resistance of apple blossom in spring. In a somewhat similar investigation, Field (1942) found no effect of soil moisture, but considered her results inconclusive.

Material and methods.

Eight experiments were carried out on seventy-three apple trees of Cox's Orange Pippin, Ellison's Orange, Worcester Pearmain and Pearl grown in pots on M.IX or M.VII out of doors and on one Cox's Orange Pippin on M.XVI in controlled environment. In the first five experiments (1948–50) water was withheld from half of the trees for a few days before freezing. The freezing tests were made at full bloom, at petal-fall and at fruitlet stages.

In Experiments 6 (twelve Pearl trees, 1956) and 7 (twenty-four Cox's Orange Pippin trees, 1957) watering ceased at various stages of floral development and a greater range of soil moisture was obtained during freezing at pink bud and open flower stages. In all experiments normal watering was resumed after freezing.

A supplementary experiment, No. 8, was carried out in August 1955 on a non-flowering, vigorous Cox's Orange Pippin tree on M.XVI. It was left unwatered for 8 days at 25° C. (77° F.) at relative humidity of about 74% and under artificial light, receiving a 16-hour day from a 200-watt Siemens combined tungsten filament and mercury vapour lamp. The light intensity at the shoot tips was about 2,700 lux.

Soil moisture determinations were made on samples collected before the freezing tests. In the first five experiments, in which trees were grown in sandy loam, 15-cm.-deep borings were made. In later experiments, trees were grown in John Innes compost No. 1 in smaller pots and a soil sample consisted of three 10-cm. borings. Soil was dried at 100–105° C. to a constant weight and its moisture expressed as per cent. of dry weight. In Experiment 8, three soil samples were taken on six different days.

Water content in plant tissue was determined on samples collected from each tree before exposure to low temperature. They consisted of five flowers at each stage of development (bud, open flower, and petal-fall), of four fruitlets or five leaves. In Experiment 8 each sample consisted of four leaves on seven different occasions.

Analyses for sugars, N and K were carried out on Cox's Orange Pippin flowers in Experiment 7. Samples of buds were collected before freezing from each tree in every treatment from the 3rd and 4th positions in the cluster. Thus they were of similar age though at a slightly different stage of development, the stage being typical for the given soil moisture treatment.

Freezing tests were made in a frost room (Slater, 1957) cooled at a rate of 1·2° C. per hour down to −3° C. (26·6° F.) which was maintained for 30 to 60 minutes. The material was then warmed at the rate of 3–6° C. per hour.

Temperature of the flowers was recorded with 40 s.w.g. copper/constantan thermocouples, either with a manually operated potentiometer, or with a 6-point recorder (Slater, 1953 and 1957).

Frost damage was recorded on the day following the freezing tests. In flowers the assessment was based on the discoloration of the base of the styles and, in fruitlets, on the discoloration of cortex and core (Modlibowska, 1957). Half of the flowers were cut lengthwise during the detailed recording of frost damage. The remaining flowers also had their frost damage recorded, but were left on the tree for investigation of their further development into fruit.

RESULTS.

For brevity only Experiment 7, which confirms clearly the results obtained in previous experiments, is described here in full detail. Twenty-four 3-year-old Cox's Orange Pippin trees on M.VII were subjected to eight treatments, consisting of withholding water from the trees on different dates corresponding to certain stages of floral development, from mouse-ear to opening of the flowers.

Effect of soil moisture on floral development and the incidence of "ghost" and "parachute" blossoms.

The earlier in the season water was withheld, the slower was the rate of drying out of the soil (Fig. 1). This was due mainly, though not wholly, to the smaller transpiration surface at the early stages of bud development. Early and prolonged water shortage greatly affected development of the plant ; leaves and flowers were smaller

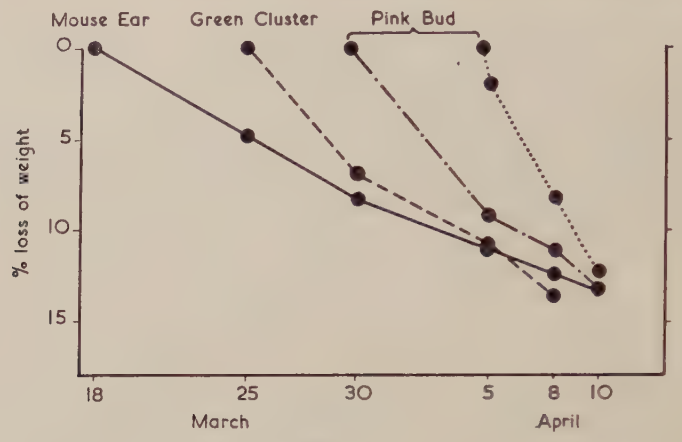

Fig. 1.

Effect of stage of development of tree on water loss from soil. Cox's Orange Pippin. Experiment 7.

and built of smaller cells, and leaves were drooping. The rate of floral development was slowed down (Fig. 2). Wilting began soon after this check, when soil moisture content fell to about 10% of dry weight. The king flowers on such trees often did not open and were of the " parachute " type, i.e. their petals did not unfold but abscissed while still stuck together after their anthers had dehisced. The youngest buds produced " ghost " blossoms, i.e. blossoms with small yellowish-green petals, and dwarf styles and anthers. Many of the buds turned pink, or even red, after freezing and watering. In buds of intermediate size even whole styles and filaments turned red. In older flowers they remained dwarf. The " parachute " and " ghost " blossoms developed most commonly on Pearl trees (Experiment 6) grown in a very dry soil (6·2 to 8·2% soil moisture) with resultant low water content of the flowers (56·7 to 75·7%). They were absent on well watered trees (Table I).

Table I.

Development of " parachute " and " ghost " flowers in relation to water content of buds. Apple variety Pearl. Experiment 6.

Water content in buds (%)	Percentage of " parachute " blossoms	Percentage of " ghost " blossoms
56·7	68·0	0·0
63·0	49·0	0·7
64·8	62·5	3·8
66·5	37·2	5·8
66·6	87·5	8·3
69·0	41·2	5·9
69·6	35·3	0·0
70·2	29·6	2·3
75·7	23·5	2·4
80·8	0·0	0·0
83·5	0·0	0·0
84·0	0·0	0·0

PLATE I.

Fig. 2.

Effect of soil moisture on blossom and foliage development of Cox's Orange Pippin. Experiment 7.

[*face p. 188*

On trees grown in relatively dry soil for a week or longer, the primary swelling of flowers into fruitlets, as recorded 3 to 4 weeks after blossoming, was much higher than on well watered trees. This was most pronounced in the variety Pearl, of which 74·3% of the flowers swelled on trees grown in dry soil, compared with only 8·6% on well watered trees. In Cox's Orange Pippin (Experiment 7) the difference was much smaller (Table II).

The June drop, however, was heavier from trees grown in dry than in wet conditions before freezing. The well watered Pearl trees developed about 4% of their blossoms to maturity whereas trees receiving the dry treatment shed their whole crop. For Cox's Orange Pippin the June drop largely offset the differences between soil moisture treatments (Table II).

The number of good seeds per fruit of Cox's Orange Pippin was lower in the two driest soil treatments (2·3–3·5) than in all the others (5·2–6·5). Most of these fruits showed russet round the stalk. This was strikingly more severe—rougher and with more cracking—on fruits from trees grown under conditions of low soil moisture than on those from well watered trees (Table II).

TABLE II.

Effect of soil moisture on fruit crops of Cox's Orange Pippin, mean of 3 trees per treatment. Experiment 7.

Soil moisture %, at freezing	Approx. % available water	Blossoms developing primary swelling	Final crop, % of blossoms	Seeds per fruit	Severely russetted fruits (%)
7·2	0·0	21·9	3·4	2·3	100·0
8·8	5·4	17·8	2·4	3·5	86·7
9·8	8·7	28·7	7·6	5·2	91·0
10·0	9·4	38·9	2·5	6·0	83·4*
11·3	13·7	26·6	1·8	5·4	88·9*
16·7	31·8	14·3	4·5	5·2	58·4
19·0	39·5	14·5	4·1	6·0	56·7
37·1	100·0	15·7	3·6	6·5	52·4

* Most severely cracked.

Effect of soil moisture upon water, N, K and sugar contents of flowers.

Reduction of soil moisture down to about 15% (i.e. removal of about $\frac{2}{3}$ of the available water) did not affect the water content of flowers (Fig. 3) or their N, K and total sugar concentrations. Drying of soil below 12% soil moisture level progressively reduced the water content of flowers and increased the sugar, N and K concentrations (Table III).

Water content of young leaves on apple shoots (Experiment 8) was also not affected by reduction in soil moisture down to 12·6% (Fig. 4). Below this point the leaves began to wilt and their water content markedly decreased.

Supercooling and freezing of flowers in relation to their water content.

The effect of water content of flowers upon their supercooling and freezing was studied with the aid of fine wire thermocouples inserted in the tissues.

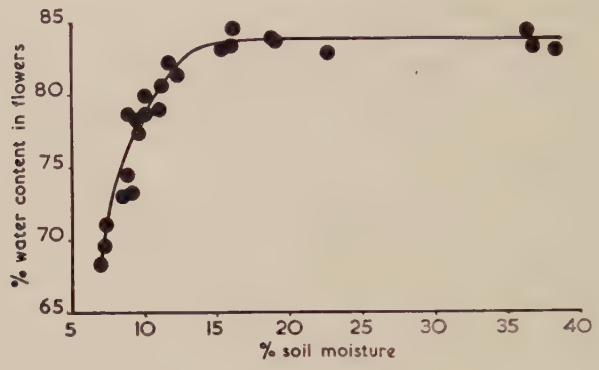

Fig. 3.

Effect of soil moisture upon water content in flowers of Cox's Orange Pippin. Experiment 7.

Table III.

Effect of soil moisture on water content, on sugar, N and K concentrations in flowers of Cox's Orange Pippin. Experiment 7.

Soil moisture, % dry weight	Water content in flowers, % fresh weight	% concentration, in water in flowers		
		Sugar	N	K
7·2	69·7	4·56	1·56	0·95
8·8	73·6	4·44	1·08	0·76
10·0	78·3	3·18	0·89	0·59
9·8	79·1	3·60	0·75	0·55
11·3	81·2	2·75	0·73	0·47
16·7	83·8	2·11	0·63	0·43
19·0	83·3	2·16	0·65	0·44
37·1	83·5	2·28	0·72	0·42

Fig. 5 illustrates two typical cooling and freezing curves of open flowers of Ellison's Orange (Experiment 1), one of a tree growing in high soil moisture (" wet " soil), the other of a tree from which water was withheld (" dry " soil).

When the blossom begins to freeze, the latent heat of fusion is liberated and the temperature curve rises above that of the air (Modlibowska, 1951, 1957). The lowest temperature reached before freezing is the supercooling point. The highest temperature reached soon after freezing indicates the freezing point.

Since the temperature difference between the freezing flower and surrounding air is due to ice formation in the flower, the area between the two curves gives an indication of the relative amount of ice formed, which can be expressed for convenience in time-temperature units (" degree-minutes "). A correction was devised for differences

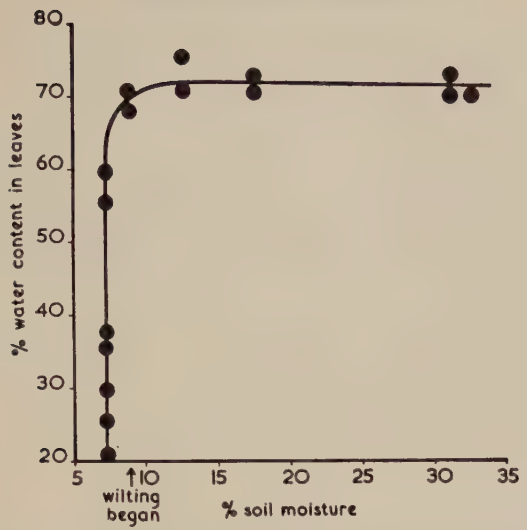

FIG. 4.

Effect of soil moisture on water content in leaves of Cox's Orange Pippin. Experiment 8.

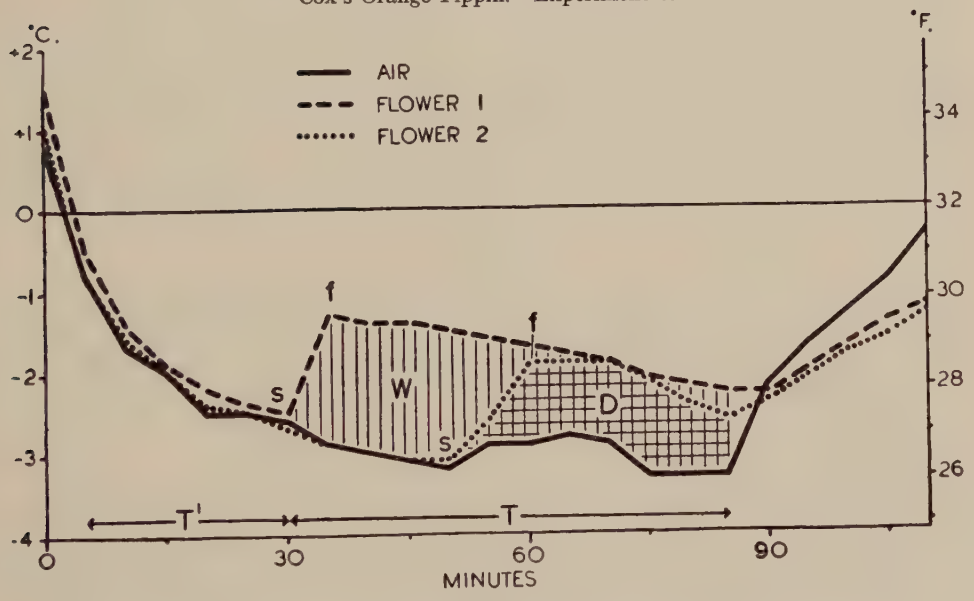

FIG. 5.

Temperature curves of Ellison's Orange flowers during a freezing test. Experiment 1.

Flower 1, of a tree grown in " wet " soil
Flower 2, of a tree grown in " dry " soil
W ||||, relative amount of ice in flower 1
D ≡, relative amount of ice in flower 2
S, supercooling point
f, " indicated " freezing point
T^1, time before freezing of flower 1
T, time during freezing of flower 1

between flower and air temperatures before freezing began and the complete calculation can be expressed as follows :

$$I=(\Sigma F-\Sigma A)-\frac{(\Sigma F_1-\Sigma A_1)T}{T^1}$$

where I = the relative amount of ice formed
Σ = sum of
F = temperature of the flower (° C.) during freezing
F_1 = ,, ,, ,, ,, ,, before ,,
A = ,, ,, ,, air ,, during ,,
A_1 = ,, ,, ,, ,, ,, before ,,
T = time of freezing of tissue, in minutes (5-minute intervals were used)
T^1 = time from zero to beginning of freezing of tissue, in minutes (5-minute intervals were used).

Supercooling and freezing.

The effect of water content of flowers upon their supercooling and freezing is summarized in Table IV. Flowers with water content below 74% fresh weight supercooled persistently down to −3·2° C. No ice formed in these flowers and no damage was caused. At higher water contents both the supercooling and (indicated) freezing points of flowers rose slightly ; also the length of time of supercooling decreased while that of freezing increased. In consequence the amount of ice formed within these flowers rose greatly. Flowers in which little ice formed (I < about 70 degree-minutes) were not killed, in spite of freezing for over one hour ; only the skin on their receptacles was lifted. This shows that, at low water content of the floral

TABLE IV.

Effect of water content of flowers of Cox's Orange Pippin upon their freezing. Experiment 7.

Water content of flowers*		Supercooling point (° C.)*	Indicated freezing point (° C.)*	Time of freezing (minutes)	Relative amount of ice, I†
% fresh wt.	mg. per flower				
69·7	58·2	−3·2	—	0	0·0
73·6	89·9	−3·2	—	0	0·0
78·3	117·5	−2·8	−2·4	75	26·5
79·1	146·2	−2·9	−2·5	70	38·5
81·2	166·4	−2·8	−2·1	70	49·0
83·8	199·1	−2·7	−1·4	90	74·0
83·3	171·3	−2·7	−1·7	105	84·5
83·5	177·6	−2·2	−1·6	115	114·5

* Water data are means of 15 flowers ; temperature data, means of 2 flowers.
† For calculation of I, see text, above.

tissues, ice formation may be confined to intercellular spaces and that the level of dehydration reached at −3° C. is not lethal. Flowers with water content over 83%, in which over 70 degree-minute units of ice formed, were killed. It is clear that the differences in the amount of ice formed are much greater than the differences in water content of the flowers.

Trees from which water was withheld early in the season showed a very strong tendency to supercool persistently and thus to be unharmed by exposure to low temperatures, e.g. all the buds of Pearl with water content below 70% supercooled persistently, while none with over 80% did so. For blossoms of Cox the threshold value for persistent supercooling was about 75% (Fig. 6). In the variety Ellison's

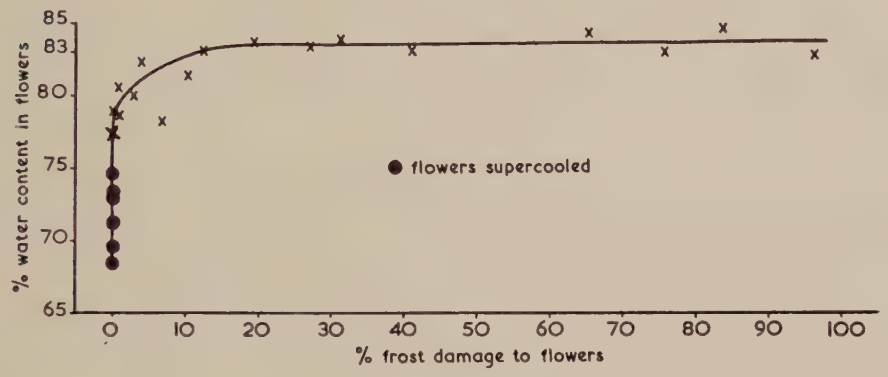

FIG. 6.

Effect of water content in Cox's Orange Pippin flowers upon frost damage. Experiment 7.

Orange a very severe soil moisture deficit (down to 5·9% soil moisture) for a few days only was responsible for persistent supercooling of all young fruitlets with an average 80·5% water content. Less severe drought conditions (about 9% soil moisture) for a short period resulted in supercooling of only a negligible proportion of flowers.

Frost damage.

When soil moisture affected the water content of blossom, it also influenced its liability to frost damage. All the supercooled blossoms were unharmed, but those in which ice had formed were damaged, thus confirming previous work on frost damage to plant cells (Modlibowska and Rogers, 1955). Among the damaged blossoms only those flowers were killed in which ice formed intracellularly within the styles and/or ovaries.

All the experimental trees grown under low soil moisture conditions had their blossoms or fruitlets considerably less damaged by frost than the well watered trees (Table V). The threshold lay between 12% and 15% soil moisture, corresponding to about 80% to 83% water content in blossom. Above the higher limit there was no correlation of soil moisture either with the water content of blossoms or with their susceptibility to frost damage (Fig. 6).

TABLE V.

Effect of soil moisture on frost damage.

Experiment	Variety	Stage of development	Wet		Dry	
			Soil moisture %	Frost damage %	Soil moisture %	Frost damage %
1	Cox's O.P.	Blossom	Wet	71·1	Dry	53·5
1	Ellison's O.	,,	,,	58·5	,,	38·7
2	Ellison's O.	,,	25·4	57·6	9·9	11·4
3	Cox's O.P.	,,	22·5	47·5	10·9	27·7
3	Ellison's O.	,,	25·2	24·1	15·7	25·4
4	Ellison's O.	Petal-fall	28·0	71·6	8·5	28·1
5	Ellison's O.	Fruitlet	26·4	83·9	8·1	37·7

DISCUSSION.

When the soil moisture was low, and the roots thus subjected to high soil moisture tension, the water content in plant tissues was decreased, the cell sap concentration was raised and its freezing point consequently lowered. Water shortage induced persistent supercooling in some of the flowers throughout the exposure to low temperature. When this occurred, no ice formed and there was no damage.

In flowers of plants grown in dry soil, ice formation started a little later and continued for a shorter period than in comparable ones grown in wet soil. Less ice was formed and was confined mainly to intercellular spaces ; consequently less damage was caused. Cell dehydration by ice formation in the intercellular spaces was not lethal at $-3°$ C., but had a protective effect against intracellular freezing at this temperature (Modlibowska, 1951).

The water content of the plant, and thus also its frost resistance, was not affected by changes in soil moisture at a high level, but at a low level there was a definite correlation.

The knowledge that only severe reduction in soil moisture appreciably increases frost resistance of fruit-tree blossom may be of some practical importance in relation to frost protection by irrigation before frosts in spring. Soil that has reached field capacity in winter would probably not dry out sufficiently in spring to affect the resistance of the relatively deeply rooted fruit trees or soft fruits. Under these conditions soil irrigation is more likely to decrease than increase frost damage, particularly to low-growing trees (dwarf pyramids) or soft fruits, because it increases the thermal conductivity of the soil. The protective effect of dry soil might, however, find an application in hardening pot plants.

As " ghost " and " parachute " blossoms occurred frequently on trees subjected to dry soil conditions for 2 to 4 weeks before the blossom period, these troubles may sometimes depend on water relations. Such blossoms can also occur on broken branches of trees under normal soil moisture conditions.

SUMMARY.

Apple trees grown in pots and allowed to reach varying degrees of soil dryness were subjected to controlled freezing cycles. It was found that, under conditions of

relatively severe drought, the water content of blossoms was reduced, the blossoms supercooled to a greater extent, less ice was formed in the tissues, and frost damage was reduced. No effect on the water content of flowers and leaves was found until about two-thirds of the available water in the soil was removed. Thus small changes in the water content of the soil, at near its field capacity, have no effect on susceptibility of apple blossoms to frost, but relatively severe drought increases frost resistance.

" Ghost " blossoms and " parachute " blossoms developed on apple trees subjected to dry soil conditions 2 to 4 weeks before the blossoms were due to open. This suggests that water shortage in the tissues is among the causes of these disorders.

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A SIMPLE METHOD FOR FOLLOWING THE CLIMACTERIC IN APPLES

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If apples are picked before they are fully ripe and are held at a constant temperature (preferably between 10° and 20° C.) it is generally found that their rate of respiration is maintained at a steady value for a time, and then increases rapidly over a period of 5 to 10 days to a value some 50 to 150% above the original level. Kidd and West (1924) have termed this sudden increase in respiration the " climacteric ". They claim that it represents a critical stage in the ripening of apples and many other fruits, and that the time at which apples are picked in relation to the climacteric can affect their subsequent storage behaviour (Kidd and West, 1933). It may, therefore, be advantageous to characterize a sample of fruit used in a storage experiment by measuring its gas exchange and finding how date of picking is related to the onset of the climacteric.

The usual technique is to measure the amount of carbon dioxide taken up by a current of carbon-dioxide-free air. For single apples the carbon dioxide may be absorbed in baryta in Pettenkofer tubes. A convenient method for bulk samples has been described by Hulme (1937).

The changes during the climacteric are so large that it ought to be possible to demonstrate them by simple and less laborious means, though sufficiently accurate for storage work where it is often only necessary to know whether the fruit is pre-climacteric, on the climacteric rise, or post-climacteric.

The following technique of measuring gas changes in a closed system is based on a method used at the Ditton Laboratory by Mann (unpublished) to measure carbon dioxide production in the presence of carbon dioxide. The use of the method has been briefly mentioned by Tomkins (1959) who has used it to estimate the rates of carbon dioxide and ethylene production of a number of different fruits. The necessary measurements can be made very quickly and, after the apparatus has been set up, it is possible to attend to 20 samples in less than one hour a day. The conditions of the experiment can also be varied according to convenience, and the layout is very flexible. The methods described are therefore only a guide to the general principle.

Method.

Samples of 18 to 20 Cox's Orange Pippin apples (about 2 kg.) were placed in 5-litre " Quickfit " reaction vessels having inlet and outlet tubes through a rubber bung in the top. This represents the maximum number of apples which can be placed in the vessel, and results in an atmosphere/fruit ratio of about 7 to 4 by volume. The units were placed in a constant temperature room (in this case 12° C.) and air was drawn through each vessel at a rate sufficiently high to prevent any accumulation of carbon dioxide. About 10 litres per hour is adequate. On alternate nights or at longer intervals the inlet and outlet tubes were sealed for 16 hours. At the end of

this time the atmosphere around the apples was examined for carbon dioxide, oxygen, or ethylene, as below.

Carbon dioxide.

The percentage of carbon dioxide in the atmosphere was measured by means of a portable katharometer, the atmosphere being circulated through the instrument and back into the container by means of a small rubber bellows. If desired, a small correction can be made for the volume of air in the instrument. The katharometer was previously calibrated against gas mixtures analysed by the Haldane method (Haldane, 1920).

In 1959, two pairs of bulk samples of apples were followed by this method, and also by the titration method for bulk samples (Hulme, 1937). Fig. 1 shows the results for one of these pairs. The curves are of the same general shape and slope, and the increases in rate of carbon dioxide production occur at as nearly the same time as is likely to be obtained with duplicate samples. The shapes of the curves indicate that the apples were picked in the pre-climacteric state.

Oxygen.

The decrease in the percentage of oxygen in the atmosphere was measured with a Beckman portable Oxygen Meter (Model D 2), which has a small rubber bellows incorporated. The instrument is calibrated directly in percentage of oxygen, and its internal volume is very small. By using the oxygen meter and katharometer together, oxygen and carbon dioxide can be measured on the same sample, and Fig. 2 illustrates one of many such pairs of curves derived from samples of 1960 fruit.

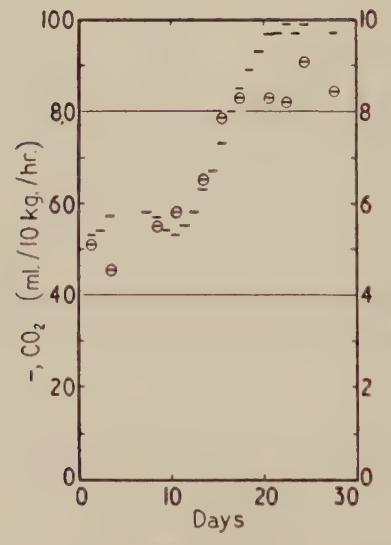

Fig. 1.

Climacteric rise on duplicate samples of apples. Comparison of the titration method and the measurement of rise in carbon dioxide per 16 hours.

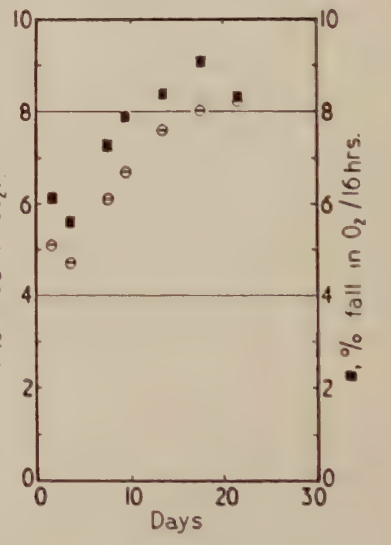

Fig. 2.

Rise in carbon dioxide and fall in oxygen per 16 hours, both measured on one sample of apples.

Again the curve for fall in external oxygen shows sufficient change to indicate clearly that the fruit was pre-climacteric.

The Oxygen Meter is commercially available, is light and portable, and probably affords the simplest of the three methods.

Ethylene.

Samples of the atmosphere were taken at the same time as the carbon dioxide and oxygen percentages were read and these were analysed by Dr. D. F. Meigh by gas chromatography (Meigh, 1960). Fig. 3 shows a typical progress curve for ethylene production per 16 hours. Production of ethylene increases very appreciably at the beginning of the climacteric rise. It probably gives the best indication of all of the commencement of the climacteric, but elaborate facilities are required for estimating ethylene.

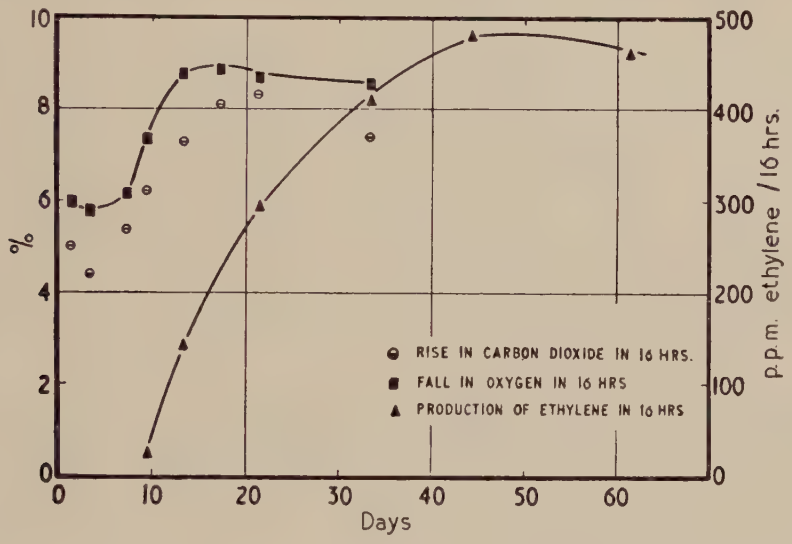

FIG. 3.

Rise in carbon dioxide and ethylene, and fall in oxygen per 16 hours, all measured on one sample of apples.

DISCUSSION.

The theoretical objection to any of these methods is that, during the time when the vessel is closed, there are changes in the surrounding atmosphere which may influence the future behaviour of the apples. It can be said that, under the conditions described (an atmosphere/fruit ratio of about 7 to 4 by volume, and a closure of 16 hours on alternate days or at longer intervals), no unusual effects have been observed. It is possible that the time of exposure of the apples to changing atmospheric conditions is too short to cause much disturbance, and this is supported by the fact that the self-depressant effects are very small. This is shown in Fig. 4, where changes in concentrations in the external atmosphere have been plotted against time. The concentration/time curves are almost linear up to at least 16 hours.

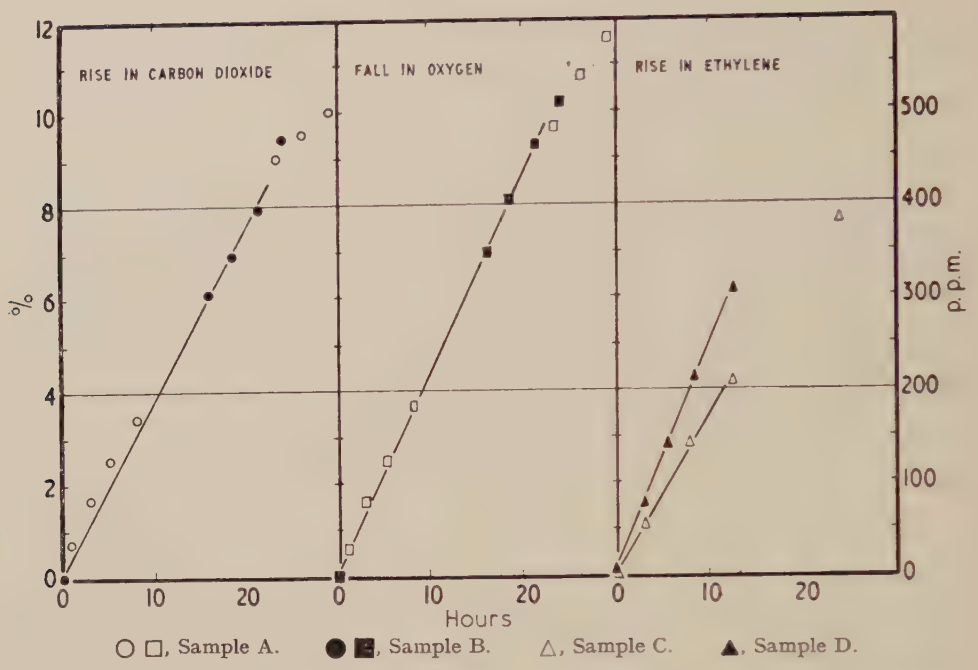

FIG. 4.

Changes with time of concentrations of carbon dioxide, oxygen and ethylene for various samples of apples. Atmosphere/fruit ratios of about 7 to 4 by volume.

In 16 hours there is also a negligible effect of build-up of carbon dioxide on ethylene production. Tubes of caustic potash solution were included in various reaction vessels in which the apples had reached their peak ethylene production. This limited the final carbon dioxide concentrations to about 1%. Table I shows the concentrations of ethylene after 16 hours compared with previous measurements. The readings were at weekly intervals.

TABLE I.

Ethylene concentrations (p.p.m.) after 16 hours, from various samples of Cox's Orange Pippin apples.

Sample	Ethylene concentrations	
	Final concentration of CO_2 about 10%	Final concentration of CO_2 less than 1%
1	313, 313	311
2	293, 300	322
3	275, 269	299
4	206, 204	209
5	212, 227	223
6	133, 134	133

It seems, therefore, that none of the effects of changes in the composition of the external atmosphere is sufficiently serious to prevent the method being used as a practical means of following the climacteric in apples.

SUMMARY.

1. A method for following the climacteric curve in apples is described. It depends upon measuring the gas conditions in a closed system.

2. Production of carbon dioxide or ethylene, or decrease in oxygen, can be used to indicate the state of the fruit. Of the three, oxygen measurements are probably the simplest.

3. Alternate aeration and stagnation, under the conditions described, do not appear to affect the form of the climacteric curve.

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THE EFFECTS OF ORGANIC AND INORGANIC NITROGEN FERTILIZERS ON THE YIELD OF EARLY POTATOES, SPRING CABBAGE, LEEKS AND SUMMER CABBAGE

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MANY vegetable growers use concentrated organic fertilizers, such as hoof-and-horn meal, in preference to inorganic for supplying nitrogen, although the former are much the more expensive. Furthermore, it is generally believed that organic materials supply nitrogen to plants more steadily and over a longer period and, as a consequence, do not lead to lush or soft growth. Losses by leaching are thought to be less than from readily soluble inorganic fertilizers, and the residual effects of organic sources of nitrogen are considered to be greater than those of the inorganic forms.

In 1954, when the experiment which is reported in this paper was begun, there was little information available about the relative effects of organic and inorganic nitrogenous fertilizers on the yields of vegetable crops. It had been shown, however, in laboratory and pot-culture experiments (3-7, 9, 10), that the organic fertilizers most favoured by horticulturists decomposed fairly rapidly when incubated with soil, and that the traditional view of hoof-and-horn meal as a slow-acting fertilizer could not be substantiated.

The purpose of the experiment was to compare hoof-and-horn meal and Nitrochalk (applied in various ways) as sources of nitrogen for vegetables in the rotation : early potatoes, spring cabbage, leeks, summer cabbage. The effects of the fertilizers were compared in the presence and absence of FYM. The results for the period 1954-59 are given in this paper.

MATERIALS AND METHODS.

Soil.

The soil is a sandy loam of the Newport series (normal phase) and is alluvial in origin. The surface soil, 0-18 in., is naturally acidic but the pH increases with depth and at depths greater than 30 in. free calcium carbonate is present. Although the soil profile does not show signs of impeded drainage, nevertheless drainage has been found to be so slow that serious waterlogging has occurred during periods of prolonged heavy rain.

At the beginning of the experiment the soil had a pH value of 6·0 to 6·2, a readily soluble (8% ammonium nitrate solution) potassium content of 60 p.p.m., a readily soluble (Morgans' solution) phosphorus content of 12 p.p.m., a total nitrogen content of 0·08% (Kjeldahl method) and a mechanical composition (International standard) of 50% coarse sand, 25% fine sand, 10% silt and 12% clay.

For two years prior to ploughing in the autumn of 1953 in preparation for the experimental crops, the site had been in temporary grass.

Design and treatments.

The experimental treatments were :

A 1 FYM at 20 tons per acre per crop
2 No-FYM

B 1 Organic N as hoof-and-horn meal ($\frac{1}{8}$ in. grist)
2 One application (N) of Nitrochalk
3 Four applications of $\frac{1}{8}$N=$\frac{1}{2}$N in total
4 ,, ,, ,, $\frac{1}{4}$N=1N ,, ,, } as Nitrochalk
5 ,, ,, ,, $\frac{3}{8}$N=1$\frac{1}{2}$N ,, ,,

The amounts of nitrogen supplied in the treatments Organic N and Inorganic N were equal. The two groups A and B were combined factorially to give ten treatments. There were four replicates and three phases, making 120 plots in all, each plot being 10×8 yd. (about $\frac{1}{60}$ acre). The rates of fertilizer applications are given in Table I.

TABLE I.

Rates of application of fertilizers in lb. per acre.

	Nitrogen	Basal dressing	
		P_2O_5	K_2O
Early potatoes	62	36	60
Spring cabbage	93	36	48
Leeks	62	36	72
Summer cabbage ..	135	36	48

All plots were given phosphate as powdered superphosphate (18% P_2O_5) and potassium as sulphate of potash (48% K_2O). The FYM was applied before ploughing and the nominal depth of ploughing was 12 in. The treatments Organic N, Inorganic N, and the first applications of $\frac{1}{8}$N, $\frac{1}{4}$N, and $\frac{3}{8}$N, together with the basal phosphate and potash fertilizers, were applied after ploughing and were worked into the plant bed—except for spring cabbage, where the Inorganic N treatment was split to give $\frac{1}{2}$N at planting in the autumn and $\frac{1}{2}$N as one application in the spring. The remaining fractional nitrogen dressings were applied by broadcasting when the weather was suitable during the growth of the crops, and not at specific time intervals.

Field technique.

Early potatoes. The variety Ulster Chieftain was found to produce potatoes of poor quality under the conditions of the experiment and was replaced after one year by Arran Pilot. The difficulty of obtaining good quality seed of this variety led to its replacement by Home Guard in 1958 and 1959.

The well-chitted sets were planted by hand, 12 in. apart in ridges 27 in. apart, in late March or early April. The crops received the normal inter-row cultivations and were harvested by hand digging from mid-June to early July. In 1954 and 1955, whole plots were harvested at one time but from 1956 onwards sub-plots were harvested at weekly intervals so that the effects of the treatments on the rate of bulking of the tubers could be assessed.

Spring cabbage. Seed was drilled in early August of each year and transplanting was carried out by hand in mid-September at a spacing of 18×18 in.; the crops received the normal inter-row cultivations. The 1955-56 crop failed as a result of frost damage and in 1959-60 more than 80% of the plants bolted before producing saleable cabbages. The variety Durham Early was substituted for Early Offenham in 1957-59 on account of its greater hardiness. The crop was cleared at one cut in late April or early May, and the total saleable cabbage was recorded.

Leeks. Seed of the variety The Lyon was drilled in early April of each year and the plants were transplanted into the experimental plots by hand in late June or early July, at a spacing of 8×16 in. and at a depth of about 6 in. At harvest in December or early January they were lifted and the roots cut off close to the stems. In 1954 and 1955 the plants were further trimmed by the removal of the ends of the leaves and the weights were recorded of trimmed and washed leeks. However, it was found to be difficult to avoid bias in the weights obtained in this way, since there was a tendency for large leeks to be trimmed rather severely whereas small plants were hardly trimmed at all. From 1956 to 1959 no leaf trimming was done although the roots were removed in the usual way. The spread of the harvesting dates during the winter of 1957-58 was greater than usual because the heavy rain during that period made many of the experimental plots waterlogged.

Summer cabbage. Seed of the variety Early Ironside was sown in cold frames in late February of each year and the plants were thoroughly hardened before being planted by hand into the experimental plots in late April or early May, at a spacing of 16×16 in. They were treated with insecticides to control cabbage root fly (14) and cabbage aphis. At harvest in mid-July, plants were cut when they had produced marketable heads, and normally three cuts were made at weekly intervals. The total weight of marketable produce was recorded.

The transplanted crops in the rotation were irrigated at planting time whenever such action was necessary to ensure satisfactory establishment.

Assessment of results.

For each crop the analyses of variance of the annual treatment mean yields have been carried out on the actual yields. Since, in any year, the yield responses to the experimental treatments generally increased with the mean yields for that year, the combined analyses have been carried out on log yields. Significance has been assessed throughout at $P=0{\cdot}05$.

RESULTS.

Early potatoes.

The visual effects of the treatments were noted during the growth of the crops and the most striking observation made in each year was that the haulms on the FYM plots were more vigorous and of a darker colour than those on the plots which had received fertilizers only. However, during periods of drought the haulms on the FYM plots did not remain turgid any longer than those on the no-FYM plots. When wilting occurred it took place almost simultaneously on all plots. Although the general vigour of the haulms was greater on the FYM plots, no specific deficiency

symptoms were seen on the no-FYM plots until 1958, when symptoms of potassium deficiency (12) were seen towards the end of June. The yields of saleable tubers per whole plot are summarized in Table II.

TABLE II.

Yield of early potatoes (mean of four replications) in tons per acre.

Fertilizer treatments*	1954			1955		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	9·4	7·0	8·2	4·3	3·5	3·9
Inorg. N	8·8	7·9	8·3	4·7	3·9	4·3
,, 4×$\frac{1}{8}$N	8·5	7·2	7·8	3·6	2·6	3·1
,, 4×$\frac{1}{4}$N	9·3	7·3	8·3	4·0	3·0	3·5
,, 4×$\frac{3}{8}$N	9·0	7·5	8·2	4·5	3·6	4·1
S.e.	±0·42		±0·30	±0·39		±0·28
Mean	9·0	7·4	8·2	4·2	3·3	3·8
S.e.	±0·19			±0·18		
	S.e. per plot=7·3% of the mean			S.e. per plot=16·9% of the mean		

Fertilizer treatments	1956			1957		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	10·6	8·7	9·7	6·3	5·3	5·8
Inorg. N	10·2	9·0	9·6	6·9	5·6	6·2
,, 4×$\frac{1}{8}$N	10·7	8·1	9·4	5·8	3·6	4·7
,, 4×$\frac{1}{4}$N	10·9	8·7	9·8	6·3	4·2	5·3
,, 4×$\frac{3}{8}$N	10·9	9·0	10·0	6·1	4·3	5·2
S.e.	±0·36		±0·26	±0·51		±0·36
Mean	10·7	8·7	9·7	6·3	4·6	5·4
S.e.	±0·16			±0·23		
	S.e. per plot=5·2% of the mean			S.e. per plot=13·2% of the mean		

Fertilizer treatments	1958			1959		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	11·1	7·8	9·4	7·5	4·0	5·8
Inorg. N	11·5	8·7	10·1	7·3	4·5	5·9
,, 4×$\frac{1}{8}$N	8·5	6·2	7·3	5·5	3·3	4·4
,, 4×$\frac{1}{4}$N	10·3	7·0	8·7	6·3	3·5	4·9
,, 4×$\frac{3}{8}$N	10·3	7·5	8·9	6·5	3·2	4·9
S.e.	±0·45		±0·32	±0·44		±0·31
Mean	10·3	7·4	8·9	6·6	3·7	5·2
S.e.	±0·20			±0·20		
	S.e. per plot=7·2% of the mean			S.e. per plot=12·1% of the mean		

Standard errors are for differences and are based on 27 degrees of freedom.

* Symbols as on p. 203.

On the whole, the effects of the nitrogen treatments were not large : the treatment $4 \times \frac{1}{4}$N produced about a 10% greater yield of tubers than treatment $4 \times \frac{1}{8}$N and a 12% lower yield than treatment Inorganic N. The nitrogen effects varied significantly from year to year but they were not obviously connected with the mean yields.

The response to application of FYM increased in 1957, 1958 and 1959 ; for the years 1954-56 it averaged 24%, for 1957 and 1958 about 38%, and for 1959 it was 81%. The data are consistent with there being a linear increase in the percentage response with time, although there are signs that 1956 was an unusual year in the series.

The percentage response to FYM was linearly related to the mean yield for a given nitrogen dressing, the response to FYM being least when the response to nitrogen was greatest ; the effect, though not large, was statistically significant. The FYM × nitrogen interaction did not change significantly from year to year.

Spring cabbage.

Observations made during the growth of the crop indicated that the poor physical condition of the soil of the no-FYM plots was likely to be a major factor in determining the final yield of produce from those plots.

The colour of the plants was greatly affected by the manurial treatments. Plants growing on the FYM plots were a darker green than those on the no-FYM plots and, in periods of very cold weather, maintained their dark green appearance whereas plants on the no-FYM plots became tinted with blues and purples. During April of each year, plots which had received hoof-and-horn meal or the lower rates of application of Nitrochalk could be distinguished quite easily by the pale green colour of the plants, the palest plants being found on plots which had received hoof-and-horn meal and no-FYM. The yields of saleable produce are given in Table III.

In the combined analysis on the log scale only the FYM × nitrogen × years interaction failed to reach significance. The mean yield in 1958-59 was about 50% higher than that of any of the others.

The response to FYM was large and variable, with no clear trend over the years. During the wet winters of 1956-57 and 1958-59 there was more waterlogging and greater crop damage and thus, in the following April, less rapid growth on the no-FYM than on the FYM plots. On the average, FYM produced an increase in yield of 54% over the no-FYM treatment. There was a fairly close relationship between the percentage effect of FYM and the mean yield for each nitrogen treatment over the years : the higher the mean yield from a particular nitrogen treatment the smaller was the percentage effect of the FYM applied with it.

The mean yields produced by treatments Inorganic N and $4 \times \frac{1}{4}$N were similar. The yield from treatment $4 \times \frac{1}{4}$N was about 27% higher than that given by $4 \times \frac{1}{8}$N while treatment $4 \times \frac{3}{8}$N produced an increase in yield of about 14% over the yield from the $4 \times \frac{1}{4}$N treatment. In the presence of FYM, treatment $4 \times \frac{1}{8}$N produced a somewhat higher yield than the Organic N treatment and, in the absence of FYM, the difference between the yields from the two treatments was about 15% in favour of the inorganic nitrogen treatment.

Leeks.

As with the early potatoes, the main differences observed during the growth of the crops were between plants on the FYM and no-FYM series of plots. Plants on the former began growth more rapidly after planting, even though all the plots were

TABLE III.

Yield of spring cabbage (mean of four replications) in tons per acre.

Fertilizer treatments*	1954-55			1956-57		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	7·0	5·6	6·3	6·0	2·1	4·1
Inorg. N	8·3	7·5	7·9	10·0	4·1	7·1
,, 4×$\frac{1}{8}$N	7·2	5·4	6·3	7·6	2·7	5·1
,, 4×$\frac{1}{4}$N	8·0	6·1	7·0	10·9	5·5	8·2
,, 4×$\frac{3}{8}$N	8·2	8·0	7·6	14·1	7·3	10·7
S.e.	±0·32		±0·23	±1·19		±0·84
Mean	7·7	6·3	7·0	9·7	4·3	7·0
S.e.	±0·14			±0·53		
	S.e. per plot=6·4% of the mean			S.e. per plot=24·0% of the mean		

Fertilizer treatments	1957-58			1958-59		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	8·7	5·4	7·0	10·2	4·7	7·5
Inorg. N	8·7	6·6	7·7	13·2	8·0	10·6
,, 4×$\frac{1}{8}$N	8·3	5·1	6·7	11·0	7·3	9·2
,, 4×$\frac{1}{4}$N	9·0	6·3	7·7	15·3	7·9	11·6
,, 4×$\frac{3}{8}$N	9·0	6·9	8·0	17·5	10·3	13·9
S.e.	±0·30		±0·21	±0·89		±0·63
Mean	8·7	6·1	7·4	13·4	7·7	10·6
S.e.	±0·13			±0·40		
	S.e. per plot=5·7% of the mean			S.e. per plot=11·9% of the mean		

Standard errors are for differences and are based on 27 degrees of freedom.
* Symbols as on p. 203.

irrigated when planting took place in dry weather. Their foliage was also a much darker green, almost a blue-green. The nitrogen treatments had no differential effects on the appearance of the plants.

The annual treatment mean yields and the relevant standard errors are given in Table IV.

The results do not show any clear trend in the yields with years either for the FYM or for the no-FYM series of plots, possibly because the year-to-year differences are too large to allow any trends to show.

The mean FYM effect was a 47% increase in yield ; it varied significantly from year to year, the largest increase being 101% in 1956, and the smallest 28% in 1955. The percentage increase in 1956 was much bigger, considering the mean yield of the crop for that year, than would be expected from the results of the other five years.

All the nitrogen effects were small compared with year and FYM effects. The mean variation of the FYM effect with nitrogen dressing, though somewhat above the purely random, was not significantly so and there was no clear pattern. The mean

TABLE IV.

Yield of leeks (mean of four replications) in tons per acre.

Fertilizer treatments*	1954			1955		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	3·8	2·7	3·3	3·2	2·3	2·7
Inorg. N	3·6	2·9	3·3	3·3	2·6	3·0
,, 4×$\frac{1}{8}$N	3·3	2·4	2·8	3·0	2·5	2·8
,, 4×$\frac{1}{4}$N	3·9	2·7	3·3	3·2	2·4	2·8
,, 4×$\frac{3}{8}$N	3·6	2·8	3·2	2·9	2·4	2·7
S.e.	±0·28		±0·20	±0·22		±0·16
Mean	3·7	2·7	3·2	3·1	2·5	2·8
S.e.	±0·13			±0·10		
	S.e. per plot = 12·6% of the mean			S.e. per plot = 10·0% of the mean		

Fertilizer treatments	1956			1957		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	8·2	3·9	6·1	12·8	7·9	10·3
Inorg. N	8·2	4·0	6·1	12·3	7·2	9·8
,, 4×$\frac{1}{8}$N	8·4	4·4	6·4	13·3	8·0	10·7
,, 4×$\frac{1}{4}$N	9·4	4·8	7·1	13·7	8·9	11·3
,, 4×$\frac{3}{8}$N	9·0	4·7	6·8	12·9	9·5	11·2
S.e.	±0·57		±0·40	±0·43		±0·31
Mean	8·6	4·3	6·5	13·0	8·3	10·7
S.e.	±0·25			±0·19		
	S.e. per plot = 12·4% of the mean			S.e. per plot = 5·8% of the mean		

Fertilizer treatments	1958			1959		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	5·7	4·3	5·0	8·7	6·6	7·6
Inorg. N	5·5	4·3	4·9	7·9	5·4	6·6
,, 4×$\frac{1}{8}$N	5·8	3·7	4·7	8·7	5·6	7·2
,, 4×$\frac{1}{4}$N	6·0	4·4	5·2	7·6	6·1	6·8
,, 4×$\frac{3}{8}$N	6·3	4·5	5·4	7·3	6·6	6·9
S.e.	±0·27		±0·19	±0·67		±0·48
Mean	5·9	4·2	5·0	8·0	6·0	7·0
S.e.	±0·12			±0·30		
	S.e. per plot = 7·6% of the mean			S.e. per plot = 13·5% of the mean		

Standard errors are for differences and are based on 27 degrees of freedom.
* Symbols as on p. 203.

effect of treatment $4\times\frac{3}{8}$N was only 7% above that of $4\times\frac{1}{8}$N and in three years they hardly differed ; there was no consistent relationship between the size of the effect and the mean yield for the year. On the average, treatment $4\times\frac{1}{4}$N outyielded Inorganic N by about 5%, but here there was a clear relationship with mean yield. It was estimated that the two treatments would give the same response at a yield of about 3·75 tons per acre and that, with a 100% increase in the mean yield, treatment $4\times\frac{1}{4}$N would give about 12% more than Inorganic N, with corresponding negative effects for decrease in mean yield below 3·75 tons per acre. A similar situation prevailed when hoof-and-horn (Organic N) was compared with Inorganic N : with the exception of 1958, the latter gave the higher yields when mean yields were low and lower yields when the mean yields were high.

Summer cabbage.

Visual observation showed that, as with leeks, the plants on the FYM plots become established more quickly after planting than those on the no-FYM plots. Throughout the growth of the crops, the plants on the FYM treatments maintained this initial advantage.

The most striking visual difference produced by the experimental treatments was in the colour of the plants. Plants on plots of the organic nitrogen and $4\times\frac{1}{8}$N treatments, both in the presence and in the absence of FYM, were much paler than all the rest and were so pale at harvest that, although they produced firm heads of reasonable size, they were of doubtful marketability. These pale plants were included in the yields of marketable produce given in Table V, since none of the plants was actually rejected by the buyers.

In the combined analysis on the log scale, all interactions including the three-factor one, FYM × nitrogen × years, were significant. The response pattern, therefore, was complex. The mean yield increased from year to year, although not by much in 1958. Although the absolute effect of FYM increased, its relative effect did not, so that there was no strong evidence of any progressive improvement in the fertility of the FYM plots through the years.

As with spring cabbage, there was a fairly close linear relationship between the percentage effects of FYM and the mean yield for each nitrogen treatment ; the higher the mean yield from a particular nitrogen treatment, the smaller the percentage effect of FYM applied with it and, conversely, nitrogen effects were larger in the absence of FYM than in its presence.

Both with and without FYM, the hoof-and-horn treatment gave yields similar to those from treatment $4\times\frac{1}{8}$N ; treatment Inorganic N gave yields similar to those from $4\times\frac{1}{4}$N. The yields from the latter averaged about 20% higher than from $4\times\frac{1}{8}$N, and yields from treatment $4\times\frac{3}{8}$N were about 5% higher than from $4\times\frac{1}{4}$N.

In April 1959, following a very wet winter, it was difficult to obtain a satisfactory plant bed for the summer cabbage crop. Soon after planting it was obvious that the plants were not growing well and the crop eventually failed. Excavation of the roots and an examination of their distribution in the soil showed that root development was poor and was in localized pockets of soil. Laboratory measurements of the pore-space distribution in the soils of the experimental plots showed that, at field capacity, there was less than 4% of air-filled pores, even in the soils from plots that had received FYM annually for six years.

TABLE V.

Yield of summer cabbage (mean of four replications) in tons per acre.

Fertilizer treatments*	1955			1956		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	10·5	8·2	9·3	13·5	9·2	11·3
Inorg. N	12·3	8·5	10·4	13·4	11·9	12·7
,, $4\times\frac{1}{8}$N	9·6	7·1	8·4	13·2	7·8	10·5
,, $4\times\frac{1}{4}$N	11·0	8·7	9·8	14·2	10·8	12·5
,, $4\times\frac{3}{8}$N	11·4	9·5	10·4	16·3	12·2	14·2
S.e.	±0·62		±0·44	±0·89		±0·63
Mean	11·0	8·4	9·7	14·1	10·4	12·2
S.e.	±0·28			±0·40		
	S.e. per plot = 6·9% of the mean			S.e. per plot = 10·3% of the mean		

Fertilizer treatments	1957			1958		
	FYM	No-FYM	Mean	FYM	No-FYM	Mean
Org. N	16·8	13·0	14·9	20·6	15·0	17·8
Inorg. N	22·4	21·0	21·7	23·0	21·4	22·2
,, $4\times\frac{1}{8}$N	19·0	17·1	18·1	20·6	14·0	17·3
,, $4\times\frac{1}{4}$N	23·5	19·0	21·2	23·2	19·1	21·2
,, $4\times\frac{3}{8}$N	23·7	19·8	21·8	21·6	20·1	20·8
S.e.	±1·45		±1·02	±1·26		±0·89
Mean	21·1	18·0	19·5	21·8	17·9	19·9
S.e.	±0·65			±0·56		
	S.e. per plot = 10·5% of the mean			S.e. per plot = 8·9% of the mean		

Standard errors are for differences and are based on 27 degrees of freedom.
* Symbols as on p. 203.

DISCUSSION.

The crops grown in this experiment can be divided into two groups on the basis of their responses to the nitrogenous fertilizer treatments. These treatments had relatively small effects on the yields of leeks and early potatoes whereas their effects on the yields of spring and of summer cabbage were large.

For the two less responsive crops, hoof-and-horn meal produced about the same yields as an equivalent amount of nitrogen applied as Nitrochalk but, for the two types of cabbage, hoof-and-horn meal was about as effective as half the equivalent amount of nitrogen applied as Nitrochalk. Warren, Cooke and Cooke (13) reported similar findings from a series of experiments carried out on a range of soils on which vegetables had been grown for many years, and which contained fairly high amounts of organic matter. In their experiments, however, crushed hoof produced rather higher yields of spring cabbage than one half of the equivalent amount of nitrogen applied as sulphate of ammonia.

The reason for the relatively low efficiency of the nitrogen in hoof-and-horn meal as compared with that in Nitrochalk for crops with a high nitrogen requirement is not

clear. It has been postulated (13) that crushed hoof may be nitrified rapidly in the soil in the autumn and that the nitrates so produced may be lost by leaching during the winter. The results presented in this paper do not support this view. For spring cabbage, treatment Inorganic N, in which one half of the nitrogen was given in the autumn and one half in the spring, produced very much better yields than treatment $4 \times \frac{1}{8}$N in which one application of $\frac{1}{8}$N was given in the autumn and the remainder in the spring. The difference in the yields was too large to be attributed purely to differences in the rate of the spring application. Hence, it seems that the autumn application of inorganic nitrogen fertilizer increased the yield of spring cabbage and, therefore, the postulate that most of the soluble nitrogen compounds present in the soil in the autumn may be lost by leaching during the winter is not supported by these results.

With summer cabbage the possibility of loss of nitrates by leaching during the winter does not arise, since the applications of hoof-and-horn meal for this crop were made in late March or early April. Several workers (2, 7, 8, 10) have stated, as a result of laboratory incubation tests and experiments on the growth of plants in pots in glasshouses, that crushed hoof can be nitrified rapidly when mixed with soil and that it cannot be regarded as a slow-acting fertilizer. However, in the most recent of these laboratory assessments, Bremner (2) used finely ground materials and an incubation temperature of 25° C. Under these conditions it was found that 70% of the nitrogen in hoof was mineralized after 40 days. The mean soil temperatures at a depth of 4 in. at Wellesbourne for April (2nd half), May, June, and July (1st half), i.e. the period when the summer cabbage crops were growing, for the years 1954-59 were respectively 8·9° C., 11·6° C., 14·4° C. and 17·2° C. These are at least 10° C. lower than the temperatures used in Bremner's work and, since the rate of nitrification is reduced by about one half by a 10° C. decrease in temperature, on this basis it would take at least 80 days for the mineralization of 70% of the hoof-and-horn nitrogen to occur. Further, since commercial $\frac{1}{8}$ in. grist hoof-and-horn meal usually contains at least 50% of coarse particles, it seems that the rate of mineralization of added hoof-and-horn meal under field conditions would be much less than under idealized conditions in the laboratory, and that this slow rate of mineralization may have been responsible for the poor growth of those crops which have a high nitrogen requirement.

However, if hoof-and-horn meal is mineralized only slowly when added to soil, it might be expected that regular applications of it would lead to a build-up of mineralizable organic matter in the soil, and that the residual effects of hoof-and-horn meal on the yield of succeeding crops would be greater than those of inorganic nitrogen fertilizers. No such difference has been detected in the experiment reported here, and Warren *et al.* (13) stated that the residual effects of crushed hoof and sulphate of ammonia were about equal. It would seem that further experiments under field conditions are necessary to determine more precisely the fate of organic fertilizers after their addition to soil.

One single application of Nitrochalk (treatment Inorganic N) at planting time produced slightly higher yields of early potatoes and of summer cabbage but slightly smaller yields of leeks than the same total amount divided into four doses and applied, one at planting and three at intervals during the growth of the crops. These results were surprising for, while it is not normal horticultural practice to apply nitrogenous fertilizer as a top dressing to potatoes, it is almost universal practice to do so to summer cabbage and, to a lesser extent, to leeks. The results obtained in this

experiment indicate that there is little to be gained by applying nitrogenous top-dressings to crops of summer cabbage, and perhaps also of leeks, provided that adequate nitrogenous fertilizer has been applied before the crops are planted. The fractional nitrogen applications ($4 \times \frac{3}{8}$N) which gave a greater total quantity of nitrogen than treatment Inorganic N produced higher yields of both spring and summer cabbage than the latter, and the response curve for the yields from the treatments $4 \times \frac{1}{8}$N, $4 \times \frac{1}{4}$N, and $4 \times \frac{3}{8}$N shows that the cabbage crops would probably have responded to higher rates of application of nitrogenous fertilizers.

There was an interaction between the effects of FYM and of the nitrogenous fertilizers. In general, the higher the mean yield from a particular nitrogen treatment, the smaller the percentage effect of FYM applied with it and, conversely, nitrogen effects were larger in the absence of FYM than in its presence. The interaction was marked and statistically significant for the two types of cabbage, small and statistically significant for early potatoes, and small but not statistically significant for leeks. Boyd (1) has recently concluded that for potatoes, in the presence of basal phosphate and potash fertilizers, FYM decreased the response to nitrogen, whereas Reith and Inkson (11) reported no such interaction.

Although this experiment was not specifically designed to measure the effect of application of FYM on the yields of the crops grown, or to assess the role of FYM in increasing the productivity of a soil, the reasons for the very large increases in yield produced by applications of FYM must be considered.

The soil on which the experiment is situated is a sandy loam which, from its mechanical composition, would be expected to be free draining and to have reasonably good physical properties. In practice, however, it is a difficult soil to maintain in a friable condition because of its poor water-stable structure and of the slow rate of infiltration of water into it. Many similar soils are used for horticultural crops and they were probably brought into such use when FYM was abundant and cheap. Many of them nowadays, when rates of application of FYM are lower than in past years, present serious structural problems.

Application of FYM to soil affects both the nutrient status of the soil and its physical characteristics. The results of the present experiment show that, over the years, there was an upward trend in the percentage effect of FYM on the yield of early potatoes but that there was no similar trend in the percentage effect of FYM on the yields of leeks, spring cabbage and summer cabbage.

To determine whether this difference in response between different crops was primarily a result of the nutritional effects of FYM (potassium deficiency symptoms were seen on the leaves of the potato plants on the no-FYM plots in June 1958 and in May 1959) samples of leaves were collected from the early potato and leek crops in 1958 and 1959.

The results of the chemical analysis of these samples (Table VI) show that the potassium content of leaves of potato plants from the FYM plots was much higher than that of the leaves of plants from the no-FYM plots, but that for leeks there were only small differences in chemical composition between leaves from the two series of plots. It would seem, therefore, that while nutritional factors and especially the supply of potassium were responsible, at least in part, for the upward trend in the percentage effect of FYM on the yield of early potatoes, it was unlikely that the growth of leeks was being restricted by nutritional deficiencies. However, since the mean increase in the yield of leeks produced by applications of FYM was 47% and it appears

TABLE VI.

Chemical composition of leaves of early potatoes and of whole leeks, as percentage of dry matter (mean of 10 samples).

	Manuring	1958			1959		
		N	P	K	N	P	K
Early potatoes	FYM	4·6	0·38	6·1	3·8	0·28	5·6
	No-FYM	4·2	0·31	2·6	3·7	0·23	3·0
Leeks	FYM	2·9	0·54	3·0	2·0	0·50	3·1
	No-FYM	2·7	0·48	2·7	2·7	0·47	2·8

that growth was not restricted by nutritional factors, it seems reasonable to conclude that a large part of the beneficial effect of FYM on the yield of leeks can be attributed to its effects on the physical conditions of the soil. This latter effect of FYM was observed in an extreme situation in March 1957 on plots which were planted with spring cabbage. The no-FYM plots were completely waterlogged and had free water standing on them whereas the FYM plots, although very wet, did not. Many of the plants on the no-FYM plots died and those which survived grew away very slowly, whereas those on the FYM plots recovered rapidly and produced a good yield of saleable produce.

When FYM is spread on the surface of a soil and ploughed in, it does not become thoroughly mixed with the soil even during the subsequent cultivations which are carried out to prepare the ground for sowing or planting. The FYM tends to remain in pockets or layers within the soil. Examination of the distribution of the roots of plants grown on the FYM and no-FYM series of plots revealed localized concentrations of roots wherever there was a pocket of fibrous organic matter in the soil, and even where FYM had been applied to the soil annually for six years, relatively few roots were found in the rest of the soil. It would seem, therefore, that FYM when ploughed into a soil may provide " pockets " in which the environment is more favourable for the proliferation of roots than in the general soil mass.

In another experiment, on the same soil type at Wellesbourne, the residual effects of a 30 tons per acre dressing of FYM on the yield of runner beans were appreciable in the year following that in which the FYM was applied (8). In the present experiment, on the other hand, where FYM was applied at the rate of 20 tons per acre per crop for a six-year period, i.e. 8 applications in all, there was no evidence of an upward trend in the percentage effect of FYM on the yield of leeks, summer cabbage and spring cabbage over the years. These rather surprising and apparently contradictory results can be explained, however, if it is postulated that the first application of 20 tons per acre of FYM raised the potential productivity of the soil to a level such that subsequent applications could not raise yields any further. This explanation would imply that the FYM residues, or FYM in the year of application, or both of these, were not being used to the full in promoting crop growth, so that it might be economically advantageous to apply FYM less frequently, or in smaller doses than was done in this experiment, and thus obtain a greater net return in terms of increased crop production for a given total amount of FYM.

SUMMARY.

In a rotational field experiment Nitrochalk produced markedly higher yields of spring cabbage and of summer cabbage, and slightly higher yields of early potatoes than an equivalent amount of nitrogen applied as hoof-and horn meal. It is suggested that the poorer growth of cabbage following applications of hoof-and-horn meal as the sole source of nitrogen was a result of the slow rate of mineralization of the organic nitrogen. In general, one application of Nitrochalk before the crops were planted gave yields similar to those produced by the same total quantity as applied in four smaller doses during the growth of the crops.

Applications of FYM produced large increases in the yield of all the crops and reduced the responses of the crops, with the exception of leeks, to the nitrogenous fertilizer treatments.

The manner in which FYM may promote crop growth is discussed. It is suggested that, on the soil of the experimental area, the effect of FYM in providing " pockets " in the soil, within which the environment was more favourable for root development than in the rest of the soil, was of considerable importance.

ACKNOWLEDGMENTS.

I wish to thank the many persons who from time to time assisted in the carrying out of this experiment and, in particular, Mr J. A. Nelder for his assistance with the statistical interpretation of the results.

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BOOK REVIEWS

PHENOLICS IN PLANTS IN HEALTH AND DISEASE. Proceedings of a Plant Phenolics Group Symposium held at Bristol in April 1959. Edited by J. B. Pridham. (Oxford: Pergamon Press. 1960. Pp. ix+131, illus. Price 42s.)

This book reports the proceedings of a symposium on plant phenolics held at Bristol in 1959 " to promote the advancement of the knowledge of phenolic compounds which occur naturally in plants ". The occurrence of phenolics in plant tissues is, of course, nothing new, but since the modern revolution in biochemical techniques they have been lifted from the status of academic oddities to a position where they are now recognized as playing an important part in many of the vital metabolic activities of the plant.

The book consists of sixteen papers contributed by workers from Germany, Holland, Belgium and the United Kingdom. Every paper is separate in itself, but they are loosely organized into four sections, each with a central theme. In the first or " General " section, there are five papers dealing with various aspects of the distribution, formation and mobilization of phenolics in plants, and their function as inhibitors of seed germination. The second section, entitled " Signification ", contains three papers describing evidence for phenolic compounds as precursors of lignin formation in plant cells. Some of the material here may have an interest outside this context. No one working with cyclic diseases of plum, for example, can be entirely indifferent to data describing seasonal changes in the phenolic content of this host. A belief that phenolics are widely implicated in the resistance of plants to disease has been growing steadily in recent years and some of the evidence for this is presented in section three, " Pathology ". The subjects include detoxication by fungi ; phenolics as inhibitors of the growth and sporulation of *Venturia* spp. ; phenolics in apples with reference to infection by *G. perennans* ; and oxidized phenols as inactivators of pectolytic enzymes produced by *S. fructigena*. Finally, under " Genetics " there are three papers describing the inheritance of anthocyanins, etc., in relation to colour variation in plants. This type of work aims at explaining " the action of genes controlling pigment production, in biochemical terms ".

It is impossible in a short review to convey the full scope of this book, and with such a wide field of subject matter it would be presumptuous to attempt a critical appraisement of it. If is safe to prophecy, however, that future generations of biologists will need to know very much more about plant phenolics than seems necessary at present. This book will enable them to get in on the ground floor. It is attractively produced and well illustrated.

J.E.C.

INTRODUCTION TO PLANT GEOGRAPHY AND SOME RELATED SCIENCES. By Nicholas Polunin. (London : Longmans, Green & Co. Ltd. 1960. Pp. 640, illus. Price 60s.)

Dr. Nicholas Polunin has taken the widest possible view of Plant Geography, and the phrase " and some related sciences " is clearly necessary in the title of this book.

It is only fair to point out, however, that it is intended that the book may be intelligible to non-biologists as well as to botanists, and in consequence a considerable amount of introductory matter is included. In fact it is not until slightly over halfway through the book, at the beginning of chapter XII, that one finds the statement that " We now come to what in some respects is our main objective ".

Extensive accounts are then given of the various vegetational types to be met with throughout the world. A chapter each is devoted to temperate, polar and tropical lands and, as might be expected from the extent of Dr. Polunin's work on the subject, that dealing with polar vegetation is particularly valuable. More unexpected are two chapters, one on the plant communities of fresh and inland saline waters and the other on those of the oceans and seas, which in effect amount to condensed introductions to botanical limnology and oceanography. Dispersal and migration, distribution patterns and what might be called historical plant geography are discussed, together with the welcome inclusion of a chapter on the geography of crop plants and weeds. Towards the end of the book there is an account of land utilization, including soil erosion, topics of perennial importance, and as an illustrative example it is good to be reminded earlier in the book of the danger that increased irrigation may worsen the salinity of desertic soils.

Earlier chapters are devoted to such matters as taxonomy, evolution, palaeobotany, economic botany and ecology, no doubt for the sake of the non-botanist. Useful features are annotated lists of references and books for " further consideration " at the end of each of the eighteen chapters and a most extensive and useful index, taking up 59 pages. The general impression, however, is of a long and verbose book, and how extensively, except for occasional reference, it will be used by pure geographers, agriculturists, intelligent laymen and botanists alike (as is suggested on the dust cover) remains to be seen.

P.S.G.

NOTICE TO CONTRIBUTORS

1. All **manuscripts** should be in double-spaced typewriting, with a good margin, and should be addressed to the Editor, East Malling Research Station, near Maidstone, Kent, England. Papers must be written concisely. Historical reviews should be as short as possible and only such references to literature as bear directly on the subject should be included. Tables and illustrations, if any, must be only such as are absolutely essential for clear presentation.

2. Authors of papers containing extensive **numerical observations** should consult the recommendations of the British Association Committee on Biological Measurements, 1927, obtainable from Burlington House, London, W.1, price 6d. Arrangements have been made whereby original data too extensive for complete publication may be deposited at the British Museum (Natural History), London, S.W.7, or with the Royal Society of Edinburgh, 22 George Street, and thus be available for consultation by other workers. Full bibliographical reference to the publication in which the results are summarized must be supplied with the data.

3. Each paper must conclude with a concise and critically correct **summary** of its actual content. It should contain any new or verified constants as well as any other critical data of permanent value but not tables or graphs. Any organism mentioned should be given its scientific name.

4. Where a paper is of a highly technical nature it should be preceded by a brief **synopsis,** in which its contents are simply and clearly stated for the benefit of non-technical readers.

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6. The **scientific names** given in the " List of Common British Plant Diseases ", published by the British Mycological Society (Cambridge University Press, 1944, revised edition in the press) and " Common Names of British Insect and other Pests " Min. Agr., Fish. and Food, Tech Bull. 6. H.M.S.O. 7/6 net) must be employed.

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10. The suggested **abbreviation** for the title of this publication is *J. hort. Sci.*

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